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TZONG J. TSENG

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COST EFFECTIVENESS ANALYSIS OF SHIPBOARD

SEWAGE MANAGEMENT SYSTEM

APPROVED BY

Geo. W. Reid

Leale Streeb

Larry Canter

DISSERTATION COMMITTEE

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ABSTRACT

The objective of this study is to evaluate current day (1973) shipboard sewage disposal devices to determine a configuration of commercial equipment that would best meet the multirequirements of shipboard environment.

Cost effectiveness techniques have been applied to identify the most cost effective commercially available systems. Unit costs (dollars per 1000 gallons treated-capital and operating) were developed using a decision weighting model which sought a measure of objectivity by delineation of the physical performance characteristics of the available alternatives. A comprehensive survey of treatment plant and hardware manufacturers was conducted to obtain data on available systems. The results of this study could help the vessel operators to make decisions when choosing disposal devices for their vessels. Furthermore, this study is one example of how system technology can be used in the solution of complex environmental quality management systems.

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CHAPTER I

INTRODUCTION

The problem of marine pollution has been discussed extensively in recent years. Marine vessels which may be classified as recreational watercraft, government vessels, and commercial vessels visit all the navigable waterways and may bring the pollutant discharges from one point to all other place along their path. When the recreational activity is high during the weekend the recreational watercraft may impose a considerable quantity of untreated waste water on the area they use.

The sanitary wastes from vessels are comprised of body waste and domestic waste. Body waste refers to the waste discharged from the human body while the other wastes entering the sanitary system from sinks, showers, laundries, and galleys are called domestic waste. The present pollution control regulations apply to human body waste only. Domestic waste can be discharged overboard without treatment at the present time. However, any waste present in the waterway may reduce the esthetic value of the water and initiate adverse ecological effects. For instance, the presence of floating materials, suspended solids, turbidity, and discoloration of the water results in an unpleasing waterway for contact recreational sports. Settleable solids can affect the environment of the stream beds by forming a sludge blanket which changes the bottom life and produces gases with objectionable odors. Suspended solids preclude sunlight needed for a healthy aquatic environment. Sanitary wastes exert an oxygen demand that reduces dissolved oxygen in the waterway. Human feces may contain the pathogens that can infect people with such diseases as typhoid, paratyphoid, dysentery, and cholera.

Characteristics of Vessel Sanitary Waste

The contents of a vessel sanitary system vary widely with time, occupancy, vessel characteristics, and the operational situation. It contains mainly body waste but, depending on the sanitary system piping arrangements, other wastes may be present in the system. Usually, the sanitary heads are flushed with fresh water, whereas in some cases brackish water or sea water may become the only diluent source.

The input to the toilets and urinals consists of urine, feces, paper, and a diluent. Excluding the flushing water, the daily per capita weight of body waste has the following average values (1):

Daily Body Waste

Daily per Capita Weight - Pounds

Waste	Minimum	Maximum	Average
Urine	2.64	3.37	3.12
Feces	0.17	0.39	0.37
Paper	0.04	0.22	0.07
Total	2.84	3.98	3.56

When domestic wastes are added to the body waste little change is brought into the physical properties of the mixture. Estimates of the pollutants in domestic waste added to body waste are as follows (2,3):

Pollutants in Sanitary Waste

Daily per Capita Weight - - Pounds

	BOD[1/]	SS[2/]
Galley Waste	0.042	0.026
Laundry Waste	0.007	0.009
Body Waste	0.150	0.198
Total	0.199	0.238

In fact, flushing water must be brought to the sanitary system in order to clean, transport, or discharge the wastes. If the diluent is taken from unrestricted waters it may include all of the pollutants discharged from the vessels plus others of municipal, industrial and/or agricultural origin. The daily per capita quantities of diluent have been found to be a function of the type of vessel, the type of sanitary system, and the practices of the operator. Body waste may be diluted with from one to thirty gallons per capita per day and domestic waste with from five to thirty gallons per capita per day. Usually, 30 gpcd flow for toilet and urinals and 65 gpcd sewage flow for combined sanitary wastes is an accepted average. However, if the total pollutants in a sanitary system come from the vessel only, the addition of diluent will not change the basic quantities of per capita pollutants, but, will alter the concentrations of the pollution.

1/. BOD, is a measure of sewage strength, Biochemical Oxygen Demand.

2/. SS, Suspended Solids.

Figure 1 shows the relationship between the pollution strength and the amount of diluent added.

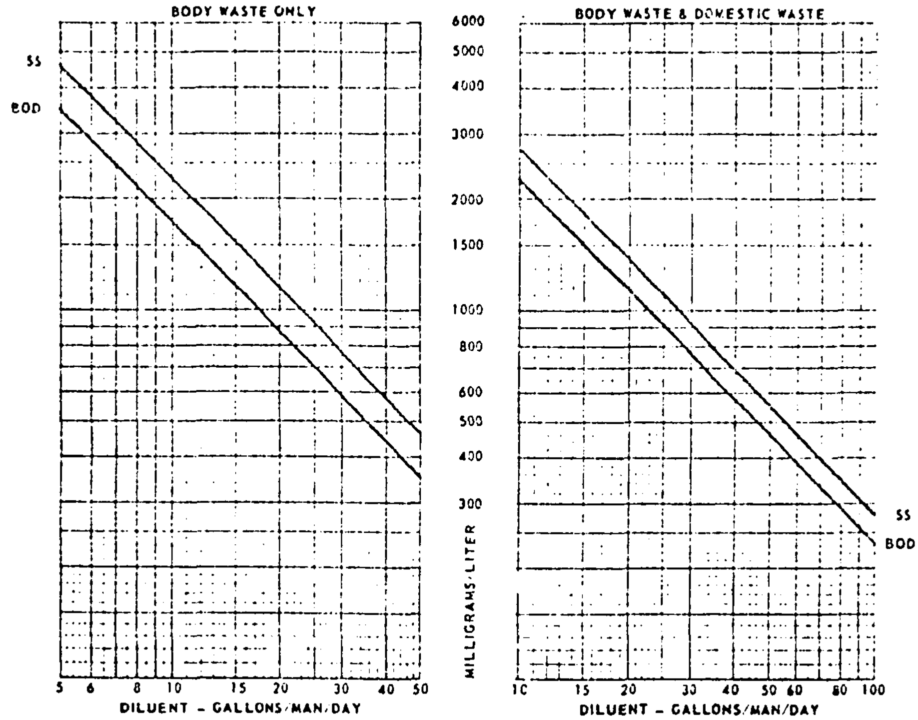

Figure 1. Effect of Diluent on Daily per Capita Waste Pollution Indices

Water Pollution by Vessel Wastes

Population aboard various types of vessels are shown in Table 1. A summary of the estimated number of vessels is contained in Table 2, and an estimate for shipboard sewage disposal device requirements is summarized in Table 3. These vessels are widely distributed over the waterways of all 50 states. The occupancy of these craft is highly variable and subject to concentrated usage during certain periods.

Table 1

Typical Population Aboard Various Class of Vessels

Class Vessel	Crew	Passengers	Total
Aircraft Carrier	4650	0	4650
Large Liners	150-180	720-2000	850-2800
Destroyer	330	0	330
Cargo Liners	40-50	10-25	50-75
Tankers	30-40	0	30-40
Bulk Carriers	20-30	0	20-30

Table 2

U.S. Ships Using Navigable Waters (1967)

Type of Vessel	No. of Vessel	Man-Year/Year
U.S. Navy	700	134,200
U.S. Coast Guard	404	6,600
Corps of Engineers	321	2,900
Maritime Administration	170	700
Tankers	2,000	*
Tugboats	4,000	*
Towboats	3,900	*
Greatlakes	209	*
Merchant Vessel	16,000	*
Recreational	1,300,000**	170,000
Total	1,327,704	513,400

* Occupancy Rate for all commercial vessels has been estimated to be 199,000 MY/Y.

** Estimated: Estimate considers age of ship backfit requirement and projected new construction. Remaining useful life varies from 20 years to longer dependent on services.

Table 3

Sanitary Treatment Unit Requirements Projection 1967-1977

Type of Vessel#	Man Capacity					
	500		200		50	
U.S. Navy	439	357	432	378	354	308
Merchant					678	605
Military Sealift					80	30
U.S. Coast Guard			15	15	149	149
Corps of Engineers					43	43
Ferry Boats	50	10			100	50

The dual columns represent maximum and minimum requirements depending on the number of new system built.

Legislation and Standards for Waste Disposal

The Water Quality Improvement Act of 1970 requires the installation of marine sanitation devices on all toilet equipped watercraft to meet performance standards promulgated by the Environmental Protection Agency. These standards require that the effluent from sanitation devices have less than 100 mg/l of suspended solids, 150 mg/l of BOD and a coliform count of not more than 240 coliform organisms per 100 ml.

A marine sanitation device is defined by Section 13 of the Act as any equipment for installation on board a vessel which is designed to receive, retain, treat, or discharge sewage. This section also describes the compliance of the vessels with the initial standards. Two years are required after the promulgation of the standards for a new vessel and five years for the existing vessels. The Coast Guard has the responsibility to promulgate regulations governing the design, construction, installation, and operation of marine sanitation devices. Prior to the effective date of Federal Standards, the states will have authority to adopt and enforce their regulations. No specified effective date has been established to date.

Two Alternatives for Shipboard Waste Management

In order to avoid discharging untreated sanitary wastes overboard, two alternatives are suggested: (1). to keep the wastes aboard temporarily and discharge them at shore facilities or in unrestricted waters, and (2). to treat and discharge the wastes into the waterway in an acceptable manner. Retaining the body waste on board requires that enough space be provided for a holding tank installation and that toilets be connected to the tank. Furthermore, this alternative is dependent on available shore-side services to completely remove the wastes and to clean the holding system. The alternative approach of treating wastes aboard and discharging them into the waterway in an acceptable condition is considerably more complex. The main challenge for systems of this type is to furnish efficient and economical treatment that will meet the discharge specifications while operating in the unique hydraulic, biological, chemical, and physical conditions of a shipboard environment. On-board treatment must also exhibit acceptable costs.

A variety of commercially developed processes are available for on-board treatment. However, significant variations exist in both cost and performance characteristics from one manufacturer to another. More specifically, they are different in the ability to produce an effluent that complies with present and possible near future federal regulations and standards; in the ability to consistently produce desired effluent quality under all operating conditions; in the ability to comply with safety standards; in support systems and equipment requirements; in space, weight, and power requirements; in supervision, operating skill, and maintenance requirements; in purchasing, installing, and operating costs; and in system automatability. Consequently, the selection of economic and effective systems from among the alternatives available is a difficult task. For cost concern, an estimated reasonable average initial and annual cost per boat for recreational watercraft and commercial vessels have been done by Maritime Information Committee, National Research Council (4) and they are summarized in Table 4, 5, and 6.

Table 4

Estimated Costs per Boat for Recreational Watercraft

Class	Length	Initial Cost $	Annual Cost $
A	less than 16'	156	45
1	16' - 26'	302	86
2	26' - 40'	619	176

Table 5

Derivation of Initial Cost Estimates for Commercial Vessels

Type of Vessel	Crew Size	$/man	$/Vessel
U.S. Flag Carriers	45	1,225	55,000
Foreign Flag U.S. Owned	45	1,225	55,000
Tugs and Towboats	8	800	6,400
Steamers 1000 Gross Tons	12	800	9,600
Tankers 1000 Gross Tons	30	800	24,000
Marine Drilling Rigs	30	800	24,000
Offshore Construction Barges	40	800	32,000
Survey Ships	10	800	8,000
Crew and Work Boat	6	800	4,800
Tenders	7	800	5,400
Fishing Boats	2.28	200	500

Table 6

Derivation of Annual Cost Estimates for Commercial Vessels

Type of Vessel	No. of Vessels	% Use in Restricted Water	* $/Vessel per year
U.S. Flag Carriers	400	33.3	10,500
Foreign Flag U.S. Owned	500	33.3	10,500
Tugs and Towboats	6,200	50.0	2,821
Steamers 1000 Gross Tons	10,000	25.0	2,100
Tankers 1000 Gross tons	300	83.3	17,500
Marine Drilling Rigs	200	100.0	21,000

Table 6(Cont'd)

Type of Vessel	No. of Vessels	% Use in Restricted Water	$/Vessel per year
Offshore Construction Barges	100	50.0	14,000
Survey Ships	300	40.0	28,000
Crew and Work Boats	1,500	33.3	1,400
Tenders	120	35.8	1,750
Fishing Boats	80,000	11.0	175

* $700 per man year per year for operating cost is assumed.

Objectives of Study

An investigation is conducted in this study to determine the most cost effective systems for on-board sewage disposal. The specific objective is to identify highly cost-effective, commercially available systems which can be selected for shipboard waste treatment and disposal.

Cost-Effectiveness analysis (5) as applied in this research work, is defined as an analytic study designed to assist a decision-maker in identifying a preferred choice among possible alternatives and involved two steps of evaluation. The first is cost evaluation which entails the delineation of all major system components and the development of capital and operating cost for each. A second is the effectiveness evaluation in which one attempts to generate a single basic measure or indicator of effectiveness using multiple considerations. The essence of cost-effectiveness analysis then compares the trade-off of cost with effectiveness to identify the most cost effective alternative.

The traditional economic analyses of engineering systems were dependent on cost consideration alone. Decision-makers initially used the least cost solutions that met required constraints. In this case, systems were measured by minimizing the cost without referring to benefits. Following this approach, evaluations emphasized net cost or net savings, with this representing the difference between total cost incurred and any resultant benefits which could be expressed in monetary units. However, it has been well known that combining costs and benefits into a single measure will not necessarily indicate the most economically efficient alternative. Thus, cost-benefit analysis which centered attention on the cost/benefit ratio as the indicator of economic efficiency was introduced. However, cost-benefit analysis is not satisfactory in evaluating wastewater treatment and disposal systems for use aboard vessels, because the overall utility of any alternative system depends on multiple criteria or measures of effectiveness (reliability, simplicity of operation, degree of automation, and others.) which can not be expressed directly in monetary units or can be measured in dollars but fail to capture the true significance. Cost-benefit analysis is only applicable when all benefit can be expressed in dollars.

Thus, selection of one system from among a group of alternatives, with respect to multiple criteria, asserts a complex problem in decision making. The difficulties come from the multiplicity of considerations which must be weighed against one another to reach a decision. This usually means a need for some type of decision-weighting model. Decision-Weighting models have been criticized by several authors. However, one can not skip the fact that the decision-maker must make a final choice. He must weigh all the diverse factors so as to reach a final overriding value evaluation and to make a choice. A methodology (63) is outline in Chapter IV to show how decision-weighting models work. Materials shown in Chapter II represent the possible techniques which can be applied in the on-board ship sewage treatment and disposal devices, as well as their advantages and disadvantages. During the evaluation, they serve as the fundamental knowledge that must be referred to when evaluating those system criteria which can only be judged from the knowledge of system's process characteristics. A comprehensive survey of disposal devices and hardware manufacturers on available systems was conducted and is shown in Chapter III. Chapter V represents the evaluation of the results of this study.

The work reported in this study is directed toward a cost-effectiveness analysis of those systems that are presented in Chapter III. The specific objective is to identify the most cost-effective systems for use as shipboard sewage disposal systems. Technical and economic data provided by the manufacturers were utilized to perform the cost-effectiveness analysis of these systems.

CHAPTER II

VESSEL WASTE CONTROL

As specified in the Water Pollution Act of 1970,

> A marine sanitation device which will prevent the discharge of untreated or inadequately treated sewage, and which will be required under these standards, is one which will prevent the discharge of an effluent containing visible floating or settleable solids; and which the effluent, without diluent other than that normally used for flushing purposes, does not contain:
> (1). Total coliform bacteria in excess of 240 per 100 ml;
> (2). Biochemical Oxygen Demand in excess of 100 mg/l; and
> (3). Suspended solids in excess of 150 mg/l.
> This would require marine sanitation devices to provide a high level of treatment which will be approximately the equivalent of the secondary treatment standards for municipal waste facilities.

A municipal sewage treatment plant is designed to manage the diluted waste that arrives at the treatment plant through the sewerage system at reasonably constant flow rate and strength of the sewage. Space is usually large enough to permit use of the full advantages of biological decomposition processes. Unlike the municipal systems, certain unique shipboard environmental factors are encountered; consequently some of the techniques used in the treatment of municipal sewage are applicable aboard ship, whereas other techniques are not successful. For example, certain conditions have to be controlled in biological processes in order to encourage the reaction rate; sedimentation is not particularly applicable because of agitation due to the ship motion; and iodine solutions are highly corrosive and are not generally applicable for disinfection.

A sound shipboard sewage treatment plant has to be able to stabilize the organic compounds, separate the solids from liquid, disinfect the liquids, dispose of the sludge effectively and economically inside the constraints of the marine environment, and be capable of immediate startup.

Appearances of Shipboard Sewage Treatment and Disposal

Vessels are different in their size and function. Some recreational watercraft may operate a few hours in fresh water, whereas sea going vessels may cruise many weeks in an ocean environment. All vessels are self-contained when underway. They are subject to all of the natural forces and resulting motions imposed by the environment. Furthermore, they have to provide life support for the people on board and serve other useful purposes. In varying degrees they must be comfortable, safe, and productive in any environment. Thus in choosing a suitable shipboard sewage treatment and disposal system certain appearances have to be considered.

The first consideration in marine sewage treatment and disposal is the limited availability of space and the reserve buoyancy to support additional machinery.

Forces which act upon a ship to disturb its equilibrium include those produced by winds, waves, turning, and weight placed off-center. In order to maintain the ship's high stability, the space in the lower part of the hull is totally allocated to machinery, equipment, and cargo. A reasonable amount of water-tight hull volume above the ship's normal waterline is also provided for this purpose. However, addition of weight high in the vessel raises its center of gravity and thus reduces the metacentric height and makes the vessel easier to capsize. In addition, liquid which only partially fills a compartment has a tendency to remain horizontal, thus when the ship is heeled, the liquid will flow to the lower side and add to the inclining moment. The movement of the liquid is an athwartship shift of weight which varies with the angle of inclination and has the same effect on vessel stability as adding additional weight. Consequently, any attempt to hold or treat the sewage on board would result in a loss either in performance or in payload capacity. It is essential that waste treatment or retention systems should be designed with minimum weight and space requirements in order to minimize the operational damages.

Power balance aboard ship is another critical factor to be considered. A typical a-c power system consists of the ship's power, the emergency power system , and the casualty power systems. Usually the ship's service power system consists of several turbine-driven generators that supply enough 3-wire 3-phase, 450-volt, 60 cycle service to distribution switch boards. However, the power requirement of the shipboard sewage treatment and disposal facilities must be compatible with the available surplus power and designed to operate only at times when the normal operating power load is at a lessened level.

As mentioned previously, the hydraulic loading on a vessel sanitary system varies widely. Figure 2 shows a typical pattern of sanitary waste flow and domestic sewage flow for a 50 men Dredge Greig. During the peak flow periods the flow rate is approximately 2 to 3 times that of the daily ayerage, whereas during certain periods the flow rate is very small. This variation of load must be considered in the design of shipboard waste treatment and disposal systems.

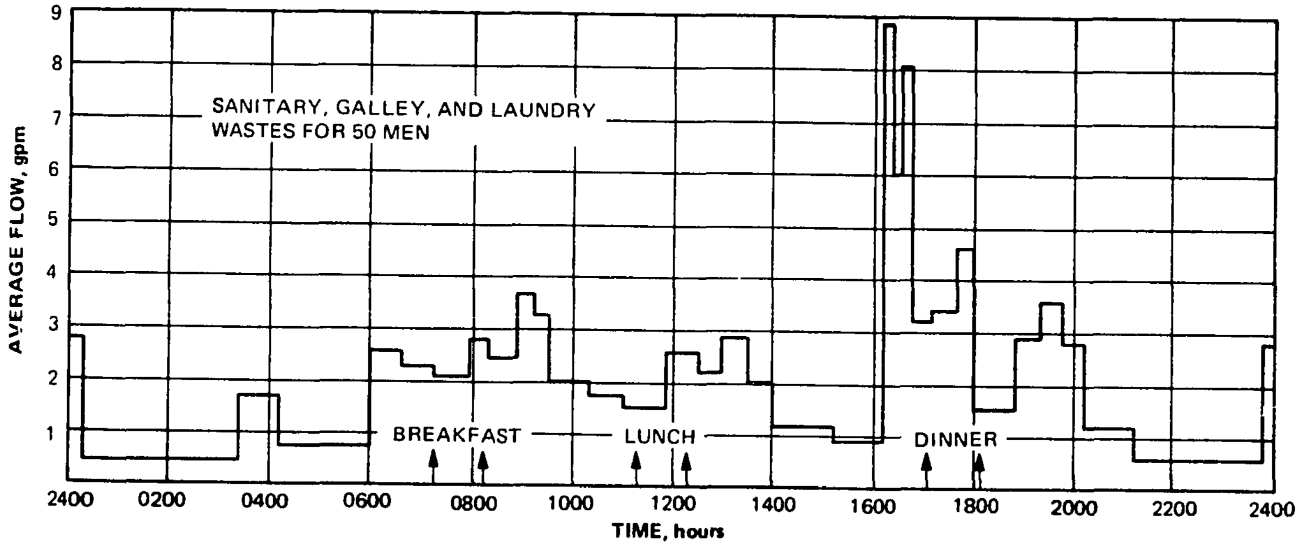

Figure 2. Wastewater Hydrograph for Dredge Greig.

Another aspect that must be considered in shipboard sewage treatment and disposal systems is the motion effects of the vessel on the treatment system. The motion due to waves in a seaway is most complex with roll, pitch, yaw, lateral drift, heave and headway or sternway all occuring, sometimes simultaneously and generally involving acceleration and deceleration.

The cause of a ship rolling in a sea is primarily one of unbalanced moments resulting from a shifting center of buoyance. The rolling angles of a ship can often exceed 30 degrees to either side with periods ranging from 9 to 30 seconds. Pitching is a phenomenon identically associated with rolling except that the axis of rotation is at 90 degrees to the rolling axis in the same plane. It is not uncommon that in the forward and aft quarters in large ships the rapid accelerations and decelerations due to pitching may reach magnitudes of 1.7 to 2 times gravity. Heaving is another ship motion which affects the apparent gravity of the ship. It is the vertical ship oscillation resulting from the vertical rise and fall of a wave. The amplitude can reach the order of ten to twenty feet with periods of from 3 to 25 seconds. Besides these motions just described, other motions include the sporadic shocks due to slamming of the bow and the vibrations induced by action of the sea or by machinery. The best location for a treatment plant is near a main or auxiliary machinery space, low in the hull. These locations are usually less affected by the heaving, rolling, and slamming effects than at the main deck or bridge locations. However, systems that are based on gravity transport of liquid, sedimentation of solids and other steady state conditions found ashore may still be affected.

Besides the above marine aspects that must be encountered in the design of a treatment system, the materials used in the manufacture and installation should be highly resistant to the corrosive effects of sewage, salt water, chemicals added as a part of the sewage handling or treatment process, toilet bowl cleaners, and the environment. In fact, each treatment system comes into contact with these environmental factors frequently. For example, piping, fittings, and valves,above and below decks, are all exposed to salt water corrosion. If the salt water is utilized as a flushing medium the problem must also be considered throughout all system elements. Any failure of the system due to corrosion will create undesirable results. Especially for the spillage of toxic or highly active chemicals, a distinct hazard both to humans and materials will be brought into the restricted shipboard spaces.

When vessel is in operation it is a self-supporting unit. Any malfunction of equipment must be repaired with the on-board tools and spare parts by shipboard personnel. For this reason, systems must be as simple as possible to reduce dependency on specialists. A high degree of reliability must be maintained and assured. Complete automation of the system is preferred in order to utilize a minimum of manpower. Shoreside cleaning, maintenance, and repair services are also demanded in ports, along inland waterways, and at marinas. Furthermore, habitability considerations require that the systems are able to operate with a minimum of noise, heat, vibration, odor, and emission of toxic fumes. Similarly, the safety of incineration elements must be considered under all possible conditions of shipboard operations.

On Board Sewage Management Techniques

A description of the various sewage management techniques which may be used individually or in combination for shipboard sewage disposal problems are contained in this section. Holding concept has been applied extensively for small watercraft, whereas large vessels may prefer treatment systems. Only the most prominent unit operations and unit processes are described. Their applicationsto shipboard environment are also discussed.

(I). Holding Tank:

Simple Holding Tank

A holding tank system requires a tank space that is situated such that wastes from most of the sanitary fixtures can be collected by gravity. The holding tank may be made of steel plate coated with a layer of epoxy interiorly; other materials such as fiber glass and rubber may be used.

The tank should be designed with a smooth interior to make it easier to clean. Bulkheads and decks can be used as tank boundaries. The tank bottom should be inclined to the pump suction. Air should be brought to the tank at a rate of 500 to 700 cubic feet per pound of BOD removed to prevent the contents from becoming septic and to keep the solids in suspension (6). Connections must be provided for washing the tank with seawater when it is not in use. Air escape must be controlled to insure that no deck is subjected to offensive odors.

Raw sewage usually passes through a comminutor prior to the holding tank. Both automatic and manual control of the pumps can be installed so that both pumps may be used when pumping the contents of the holding tank. A tank high-level audible and visual alarm should be provided. The sewage is aerated and maintained in suspension within the tank. When the discharge connections have been connected to a shore facility or barge, or when open sea is reached, the pumps are started manually and evacution of the tank is accomplished.

Vacuum Collection System

The vacuum collection system uses air instead of water for the transport of sewage. In this system the raw sewage piping and collection tanks are held under a suitable constant vacuum. Toilets can be connected to the piping by means of discharge valves controlled by the flushing mechanism of each toilet. With the discharge valve open, atmospheric air enters the system and the sewage is pushed through the pipes, in the form of a liquid plug, to a collection tank.

The vacuum system provides a large reduction in the volume of raw sewage to be held. Since gravity transport is not involved, pipes can be placed without slopes and worked around obstacles. The collection tank can be emptied in unrestricted waters either by pumping or by compressed air. The contents may be sterilized before discharged overboard. Alternatively, the contents may be pumped into municipal sewers or to a barge while the ship is in harbor.

In order to sustain the high velocity of transportation byvacuum and to retain the integrity of the liquid plug, it is necessary to use piping with low friction and to avoid all restrictions and abrupt changes in the direction of flow.

Recirculating System

A recirculation system is a variation of the holding tank. The core of this system is a tank containing all of the necessary pumps, valves, and filters to enable the unit to be installed in the deck of the wash room. The inside of the recirculation tank is divided into dirty and clean sections by a static filter. All waste is directed into the dirty side and all flush drawn from the clean side. When discharging to the waste collection system, the water is drawn from the dirty side inducing the clean water to backwash the static filter.

Holding tanks appear to have appropriate application aboard all sizes and types of vessels. The devices can completely prevent the discharge of sewage from a watercraft into the water and at the same time the operation of the holding tank is subject to a minimum of mechanical or human failure. However, the feasibility of the holding tank approach will depend on the anticipated flow on the vessel, repiping required to divert the sanitary waste into the holding tank, availability of pumpout facilities, the possibility of reduced resulting revenue from on board retention practices, and availability of odor control chemicals.

In a vacuum collection system, because of reductions in the diluent volume, the only suitable pumping device for transferring this highly viscous mixture will be a positive displacement type. Grease may coat the pipe interior and decrease the effective pipe diameter. Moreover, using air as a transport medium requires a separation of raw sewage from other liquid wastes, hence, the piping system must be separated from the galley and sink systems. Repiping of wastewater lines represents a significant cost, and cost to divert a central location through the hull and interior of the ship could be large. Separation of flush water from other flows to accomodate holding tank will represent significant cost factors.

(II). Treatment Techniques:

Particle Disintegration

Particle reduction can be achieved by applying hydrodynamic and mechanical forces to the solids (7). When choosing appropriate equipment to reduce sludge particles mechanically, consideration on certain factors, such as, size of feed and finished products, viscosity of the mixture, chemical composition and corrosion, and capacity, prior to selection of equipment, may avoid pitfalls and point to the best advantages.

The most applicable comminuting devices utilized aboard ship sewage treatment and disposal systems are grinders and pump grinders. Still,some other types of comminuting devices like cutters, dicers, mills and classifiers may also be considered as potential candidates.

Comminuting devices are usually installed prior to the aeration surge tank, coagulation tank, and filtration device.

One of the purposes of particle reduction to a uniform mixture is to achieve an efficient biooxidation process. Space availability is always a problem on board. By comminution, minimum pipe size can be utilized for transport of the wastewater without clogging. Atomizing the suspension for sludge destruction in an incinerator by converting the organic content into water, carbon dioxide and inorganic solids has been used very often on board. Comminution is necessary to reduce the possibility of clogging through nozzles.

Colloidal content may increase after the comminution process. It will consume more coagulants or decrease the efficiency of screening, filtration, settling, and centrifugation.

Particle Aggregation

To bring about particle aggregation (8), steps must be taken to reduce the effect of particle surface charge and then to bond together those coagulated particles to form settleable or filterable solids. Coagulation can be accomplished by the addition of chemicals that will form hydrolized metal ions, or by addition of potential-determining ions which will be taken up by or will react with the colloid surface to lessen the surface charge. Polymer, polyelectrolytes will also bring about the removal of particles through adsorption and bridging.

The action of polyelectrolytes may be divided into three categories. In the first category, polyelectrolytes act as coagulants by lowering the charge of the wastewater particles. The second mode of action of polyelectrolytes is inter-particle bridging. In this case, polymers which are anionic and nonionic become attached at a number of adsorption sites to thesurface of the particles found in the settled effluent. A bridge is formed when two or more particles become adsorbed along the length of the polymer. Bridged particles become inter twined with other bridging particles during the flocculation process. Flocculation is hastened by stirring the wastewater to increase the collision of coagulated particles. It requires definite time intervals to be accomplished. The size of the resulting three dimensional particles grows until they can be removed easily by sedimentation.

The third type of polyelectrolyte action may be classified as a coagulation-bridging phenomenon, which results from using extremely high molecular weight cationic polyelectrolytes. Besides lowering the charge, these polyelectrolytes also will form particle bridges, as discussed previously.

The conventional chemicals added as coagulants are lime and aluminum (III) and iron (III) salts. The numeral "III" refers to aluminum and iron which are chemically combined with 3 valanced bonds. Lime reacts with the bicarbonate alkalinity of wastewater to form calcium carbonate also reacts with orthophosphate to precipitate hydroxyapatite. Lime is, of course, an alkaline substance which raises the pH of the waste water. When alum is added to wastewater in the presence of alkalinity, a hydrolyzing reaction occurs. The aluminum hydroxide floc is a voluminous, gelatinous floc which enmeshes and adsorbs colloidal particles on the growing floc.

Potential applications of coagulation in shipboard sewage treatment systems may include:(1). the removal of colloidal substances prior to adsorption, filtration, sedimentation, and ultrafiltration, (2). the removal of colloidal precipitates formed in phosphate precipitation processes, (3). the removal of dispersed microorganisms after a brief biooxidation process, and (4). direct coagulation of the waste.

Polymeric species are formed when quantities of iron (III) and aluminum (III) salts sufficient to exceed the solubility limits of the metal hydroxides are utilized. Their properties are greatly affected by the solution pH and the concentration of coagulants. If these salts are added to a poorly mixed system, local variations in pH and coagulant metal ion concentration will produce a more heterogeneous and less reproducible variety of polymeric species than a well-mixed system.

Polymer formation is followed by polymer adsorption. This is also a rapid reaction. Efficient use of these inorganic polymers requires that they be uniformly adsorped on the colloidal particles, Thus mixing facilities are necessary in order to perform a good coagulation process.

Solid-Liquid Separation

The separation of solids from liquid is essential in shipboard sewage treatment systems. Water may be reused or discharged overboard if the solids content has been efficiently reduced. Numerous methods are available to perform the separation. Figure 3 shows useful ranges of separation processes.

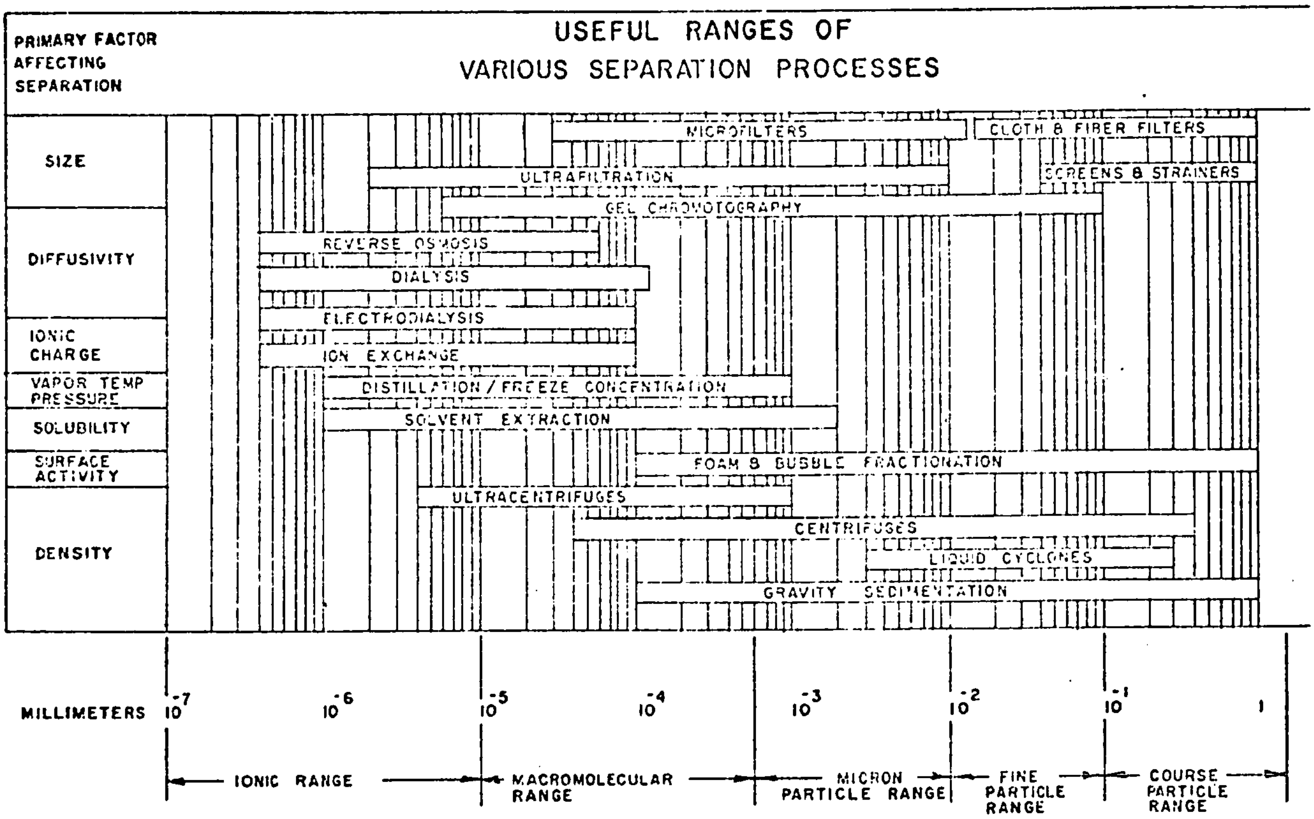

Figure 3. Useful Ranges of Separation Processes.

(A). Sedimentation:

Sedimentation has been applied to shipboard sewage management system in any of the following variations:

(a). horizontal flow chambers with internal flocculation;

(b). horizontal flow chambers with external flocculation;

(c). upflow chambers with internal rapid mixing and flocculation; and

(d). solid contact units with recirculation of settled solids.

In many cases, gravity separation of settleable solids has been shown to be a simple and economical process. However, because of the sensitivity to the loadings, it may also have the potential to destroy plant reliability. If an immediately down-stream filter or adsorption process can not tolerate high solids loading, gross carry-over of solids from the clarifier may cause the entire system to be removed from service. Moreover, the apparent gravity of the ship is highly sensitive to the ship's motions. An inconsistency on the performance is expected for all kinds of gravity separation.

Upflow clarifiers have experienced difficulties in maintaining the sludge blanket (9). In order to prevent massive overflow of floc, constant loading with suitable controlled overflow rate may be required and may limit polyelectrolytes as the only suitable coagulant.

Septicity is another problem. It requires that a certain percent of the sludge throughout be removed constantly from the sludge blanket.

(B). Filtration:

(a). Screens:

Only screens with mesh and coiled springs may find importance in shipboard sewage treatment systems. Devices in the form of stationary screen, screen conveyor, and vibrating screen are applicable.

(b). Precoat Filtration:

The treatment of wastewater to remove the suspended solids from the liquor by means of filtration can usually be made more efficient through the use of filteraids (10). The filteraids can be applied in any one of a number of different ways. Some of these methods are: as an additive to the slurry to change the filterability; as a precoat or thin layer of filteraid on a filter cloth to form a more efficient septum, that is, a barrier to solids passage; as a very thick layer on a filter cloth or screen on a rotating drum which is shaved off as it becomes coated with solids; or as a thick precoat through which solids migrate slowly rather than from a layer on the septum's surface.

The filter medium used in a precoat filter is a thin layer of diatomaceous earth which is wasted at the end of each filter cycle. Diatomaceous earth is a very soft mineral composed of billions of tiny fossils. Unlike most fossil formations, diatomaceous earth consists mainly of silica, a chemically inert substance.

When a diatomaceous earth filteraid is mixed with water and filtered out, the irregular (but symmetrical) shapes of each diatom form a rigid bulky filtercake, or precoat, which is quite incompressible and consists of approximately 10 % solids and 90 % voids (11). Such a precoat becomes a screen having extremly tiny openings. The problems of passing liquid through such a fine screen are minimized because the many openings compensate for their small size.

Only solutions containing a relatively few rigid solids can be effectively filtered through a precoat alone. More commonly, sufficient diatomaceous earth filteraid to form a rigid, incompressible cake is also added to the unfiltered liquor. Filtration removes both the filteraid and the solids together, while forming the porous, rigid, incompressible filter cake of diatomaceous earth. Because of the bulky nature of diatomaceous earth a small amount is required, averaging 0.5 % of the liquor weight .

Usually, the diatomaceous earth filteraid is operated with a vacuum filter or pressure type filter. Continuous processes require proportioning equipment which is capable of maintaining the same percentage of addition throughout the operation.

For economical and efficient filtration, the amount of solids loading should be kept as constant as possible. A high quality product with no detectable BOD and only a trace of suspended solids has been reported as secondary effluent is treated with diatomaceous earth filter. This may allow the product to be reused aboard. The high percentage of void space of the diatomaceous earth permits higher flow rates and reduces the filter area and space and also affords maximum filter cycle to increase liquor volume per unit of time. All of the advantages noted above contribute to reduced operating costs. Increased production per unit time means lower unit costs. Wear and tear of filter cloth, as well as washing, is greatly reduced so that maintenance costs are sharply decreased, and also less expensive grades of cloth can be used. Furthermore, with increased capacity, longer cycles and the resultant greater production, less equipment may be required. This decreases the capital investment and maintenance costs. However, certain disadvantages are associated with the precoat filtrationdevice. They include: the sensitivity to air bubbles and sudden changes in pressure, vibration, or turbulence near the filter cake, thus causing the filtrate to become turbid until the upsetting influences have corrected; the sensitivity to variation of suspended solids loadings require a sophisticated control system; high initial cost limits its potential application on board; and specially trained personnel are required for operation.

(c). Membrane Filtration Processes:

The membrane processes produce high quality effluent by forcing the liquor through membranes at suitable pressure. A broad variety of membrane configurations have emerged. However, the basic membrane processes are , membrane filtration, ultrafiltration, reverse osmosis, electrodialysis, and dialysis.

The membrane filtration is capable of removing the suspended solids and colloidal solids from the wastewater stream. The separation occurs based on the physical size of the particle in relationship to the physical size of the pores contained within the membrane. The membrane pores are relatively large compared to the other membrane processes. The separation represents a true filtration mechanism with water passing through the uniform pores of the membrane filter under a driving force of a modest pressure differential (10 psi). Membranes with pore sizes down to 1 micron have been reported.

Ultrafiltration is a process which is able to remove dissolved high molecular weight organic materials from the waste stream. Pore sizes are in the range of 10 Å. The driving force moving water through membrane is also an applied pressure, but substantially high, ranging up to as high as 600 psi.

The reverse osmosis process produces desalted water by forcing the liquor through semipermeable membranes at high pressure. These membranes are more permeable to pure water than to dissolved salts. The process reverses the normal osmotic process by increasing the pressure on the concentrated side of the membrane until flow takes place from the concentrated to the diluted side. The reverse osmosis process is capable of completely removing the dissolved organic solids from the stream and resulting portable water. It is obvious that the membrane process has a high potential to meet the future no-discharge requirement. However, the extremly high initial and operating costs and limited capacity of available commercial units restrict the current application in any wastewater treatment field.

(C). Flotation:

The removal of finely divided colloidal and suspended matter may be accomplished by flotation, especially in conjunction with the use of polymers.

Separation in this type of unit operation is accomplished by introducing fine gas bubbles into the liquid phase. Clean air is the most frequently used gas, whereas chlorine may be applied for both the purposes of disinfection and fine gas bubble generation. Bubbles of H_2 and O_2 have also been generated by electrolysis in what is termed electroflotation (7). The bubbles attach to the particulate matter, and the buoyant force of the combined particle and gas bubbles is great enough to cause the particle to rise to the surface. Particles that have a higher density than the liquid can thus be made to rise. Once the particles have been flotated to the surface, they can be collected by a skimming operation.

Chemical flotation aids may be added to the feed before the waste stream enters the flotation tank, or added to the air-water mixture after the mixture passes the pressure reducing orifice near the bottom of the tank.

Two types of flotation have been commonly used, that is, dispersed air flotation and dissolved air flotation. In dispersed air flotation, gas bubbles are generated by introducing the air with mechanical agitation impellers or with sparging air through porous media. Bubble size is of the order of 1000 micron in diameter. The bubble distribution in the tank is not uniform and the bubble size is so large that a great tendency of the bubble to shear the solids exists. Dispersed air flotation is not efficient in wastewater treatment practice. In dissolved air flotation, bubbles are produced as a result of the release of a gas from a solution supersaturated with the gas. The average bubble size ranges from 70 to 90 micron. There are two types of contact between the gas bubbles and particles. The first type is predominant in the flotation of flocculant materials and involves the entrapment of rising gas bubbles in the flocculant particles as they increase in size. The bond between the bubble and particle is one of physical capture only. The second type of contact is one of adhesion . Adhesion results from the intra-molecular attraction exerted at an interface between two phases. The entrapment of gas bubbles is promoted by the use of coagulating chemicals. They increase the floculant structure of floated particles, thereby facilitating the capture of bubbles.

A typical flotation unit with supporting equipment will contain a sludge feed pump and meter, polymer mix and feed equipment, flotation thickner, electrical control panel, air compressor and receiver, and a sludge pump. A polyelectrolyte solution is fed at 0.2 to 1.0 %. The air compressor should have 4 to 5 times the capacity of the average requirements of the air receiver. The flotation unit recirculation system normally operates at 60 to 70 psig. Solids captures up to 97 % have been reported. The short retention saves space and weight requirements as compared to sedimentation units. However, the performance efficiency requires a relatively constant influent flow, that is, if there is an overload of solids, there will not be enough air to float the sludge. A hydraulic overload will result in scouring of solids off the bottom of the sludge blanket by the high velocity flow of the water beneath.

In order to reduce odor problems the sludge removal rate requires adequate adjustment. Because of power cost and the requirement for flotation aids, only secondary effluent should be floated in a wastewater treatment unit, not primary sludge, which is effectively handled in other separation devices.

(D). Centrifugation:

Centrifugation can be applied for the dewatering of raw primary sludge from clarifiers, wet oxidation sludge prior to incineration, biological activated sludges, sludge from physical chemical treatment processes.

The machines used most widely in sewage treatment are solid bowl, disc, and basket. Each performs one of the three functions: clarification, classification, or separation (15).

The solid bowl consists of a solid cylindrical bowl, supported between two bearings, and fitted at one end with a conical dewatering section. At the opposite end there is a dam to regulate the liquid depth in the bowl. A screw conveyer is located concentrically in the bowl and driven at a speed different from the speed of the bowl by means of an external gear assembly. Feed is introduced to the centrifuge, and the centrifugal forces developed by the speed of the bowl separate the heavier solids almost immediately. As the liquid flows through the conical section toward the dam, progressively finer solids settle on the bowl wall and are removed. A screw conveyer continuously moves the solids to the conical section. The solids are moved from the liquid section up to the conical section and permitted to drain before being discharged from the machine. The solid-bowl centrifuge performance is affected by the following parameters: centrifugal forces, liquid level inside the bowl, and the speed diference between the bowl and conveyer. Increasing the RPM will increase the degree of dryness of the solids. Depth is maintained as shallow as possible, provided that the wall turbulence and the velocity of the liquid will not scour the particles back to the liquid phase and reduce the recovery. The speed differential must be sufficient to convey the solids out of the bowl and yet not enough to scour them back into suspension.

Disc-type centrifuges consist of a number of conical discs stacked one upon another, give a tree effect. Each disc acts as a separate centrifuge of very low capacity. The space between discs must be large enough to allow the solids to pass through, yet small enough so that the solids will have only a short distance to travel before they settle. The settled solids are removed as they slide down the underside of the upper disc and pass to the outer perimeter of the bowl.

Once the solids are at the outer perimeter of the bowl they are concentrated by the centrifugal force and pass out of the bowl shell in the form of a concentrated slurry, through peripheral nozzles. Meanwhile, the liquid passes inward in a channel to the upper end of the bowl, where it is collected separately in the upper cover. The performance parameters for the disc type machine are centrifugal force, disc spacing, and nozzle size. A very minimum spacing between discs is not always advantage , because plugging problems can occur. The nozzle size is significant in that it will determine the retention time of the solids in the outer bowl, and therefore can directly affect the concentration of the slurry being discharged

The advantage of the disc centrifuge is that the high centrifugal force developed in this type of unit makes it suitable for breaking emulsions and particularly for the removal of the fine solids. However, the feed slurry requires screening to remove large solids and fibrous material which may clog the discharge nozzles on the machine.

The basket centrifuge is a tubular type centrifuge with a perforated bowl, and its operation is very similar to the solid bowl in that the solids are caused to settle out along the vertical walls by centrifugal force. The solids are removed periodically from the inside of the bowl.

The use of centrifuges for solid-liquid separation offers some advantages over alternate means such as vacuum filtration. Advantages for centrifugal dewatering include: much lower investment cost for the dewatering facilities; smaller area requirement with a minimum of auxiliaries. In addition to the centrifuge, only a feed pump and polymer feed system may be required; procedures for start up and shut down are simple and can be accomplished in a short time; it can tolerate variation in feed condition; the centrifuge dewatering system is easily automated to fit into any other process requirements such as constant feed to the incineration unit; and it is not affected by climatic conditions. However, certain disadvantages are associated with the system. They include: high power consumption, high maintenance costs, and high operating costs limit its wide application; grit or coarse solids must be screened out before feeding to the system; raw sludge may plug the disc machine by building up grease on the discs and stopping the function of the centrifuge.

Disinfection

In the area of wastewater treatment, disinfection most commonly is accomplished through the use of chemical agents, physical agents, and radiation.

Chemicals that have been used as disinfection agents include phenol and phenolic compounds, alcohol, iodine, chlorine and its compounds, bromine, ozone, heavy metals and related compounds, and hydrogen peroxide, etc. The most common disinfectants used on board are chlorine and its compounds.

Physical disinfectants that can be utilized are thermal energy and light. Heating water to the boiling point will destroy the major disease-producing, non-spore-forming bacteria. Heat is not a feasible means of disinfecting large quantities of wastewater because of the high cost. Freezing and freeze drying are effective methods for preservation of bacteria. Repeated rapid freezing and thawing usually results in bacterial kill due to rapidly induced changes in osmotic pressure. This technique for disinfection is of little practical significance for wastewater treatment.

Special lamps that emit ultraviolet rays have been used successfully for the sterilization of small quantities of water. The efficiency of the process depends on the penetration of the rays into water. It is thus difficult to use ultraviolet radiation in aqueous systems, especially when particulate matter is present.

Use of ultraviolet light for disinfection has some definite advantages. Because nothing is added to the water, no desirable quality will be changed and no taste or odors result from the treatment. A significant disadvantage of ultraviolet as a means for disinfecting large scale water supplies results from the fact that it provides no residual protection against recontamination.

(III). Other Waste Disposal Methods:

Wet Oxidation

Wet oxidation units are based on the principle that organic substances may be oxidized under high pressures at elevated temperatures with the sludge in a liquid state by feeding compressed air into the pressure vessel (16). In other words, it involves burning of organic matter in the absence of flame and in the presence of liquid water. The purpose of high pressure is to prevent the vaporization of waste so that combustion by use of dissolved molecular oxygen can occur. Combustion is not complete; the average is 80 to 90 % completion. Thus, some organic matter, plus ammonia, will be found in the end products. Maximum operating temperatures for the system vary from 350 to 600 ^{o}F, with design operating pressure ranging from 150 to 3,000 psig.

The sewage passes through a macerator and is then heated in a combination surge tank and heat exchanger. The purpose of maceration is to make the particle size suitable to pass the openings in the equipment; it is not required for satisfactory oxidation. A high pressure pump takes suction on the surge tank and discharges the wastewater at the pressure necessary to obtain the percent organic removal desired. Compressed air is injected into the high pressure wastewater before the water is heated in a second heat exchanger to a temperature necessary to sustain a high temperature, high pressure, spontaneous chemical oxidation reaction in the reactor. The temperature of the wastewater is controlled by regulating the reactor effluent flow through the second heat exchanger. The percentage of flow that does pass through the exchanger is transferred to the gas separator where the gases and steam produced by the oxidation reaction are separated from the aqueous phase. From the separator the aqueous phase is passed through the surge tank where it heats the incoming wastewater. Ash and noncombustible solids are removed in the ash separator before the aqueous phase is discharged overboard. During the start up, the incoming mixture is heated to the reaction temperature by steam introduced into the heat exchangers. After oxidation is initiated, steam heating is discontinued and the oxidation products leaving the reactor are at temperature of 220 to 320 ^{o}C.

The wet oxidation process is capable of removing a major portion of the organic solids from the wastewater through chemical oxidation, and it is uniquely suited to the treatment of waste liquors which is difficult to dewater and sludges where the solids are a small percent of the liquid carrier. Given the proper temperature, pressure, reaction time, and sufficient compressed air or oxygen, it is capable of leaving only a small volume of solids or oxidized material which must be removed from the system to a holding tank.

However, certain disadvantages are associated with the wet air oxidation process. They include: inability to oxidize dissolved organics when present in very dilute concentration; production of offensive odors and associated air pollution by gases from gas separator; requirement of sophisticated controls, frequent maintenance, and experienced supervision; inability to reduce and remove dissolved inorganics such as, nutrients from the wastewater; and air which must be supplied to the reactor under pressure is costly. It is important to achieve complete utilization of the oxygen in the air supply.

Activated Carbon Adsorption

When the entering water contains dissolved organic materials, activated carbon has the ability to remove these materials selectively by adsorption. Adsorption is a phenomenon in which organic molecules cling to a surface with which they come into contact due to forces of attraction between the carbon surface and species' molecules. The use of surface energy to attract and hold molecules is physical adsorption. Species' molecules diffuse to the liquid-carbon interface due to the concentration gradients at the bulk liquid phase and the interface. The fact that activated carbon has an extremely large surface area per unit weight (on the scale of 1000 m^2/g) makes it an efficient adsorptive material. The two mostpopular sizes of granular carbon for wastewater treatment are 8 x 30 mesh and 12 x 40 mesh. The finer material has a higher rate of adsorption, but also has a higher head loss per unit depth of bed, and since the beds have lower porosity, they have a tendency to plug with materials filtered out of the wastewater.

Two basic fixed bed systems have been developed for waste water treatment purposes, the downflow bed and the upflow bed system (17).

(a). Downflow Bed System:

A fixed column is used as a means of contacting wastewater with granular activated carbon. The water is applied at the top of the column and withdrawn at the bottom. The carbon is held in place with a screen at the bottom of the column. The purpose of this downflow system is to remove the dissolved organics by adsorption as well as the flocculated materials by filtration. Single column systems, series column systems, parallel column systems, and combined series-parallel systems can be operated using this type of carbon bed. Single column systems may not fit the on board wastewater treatment system because of height and size. The series column systems feed the effluent from the first column to the next and end up with a high quality product. The parallel column system, which is placed on stream at evenly spaced intervals, receives the same feedstock and discharges into a common manifold. With this arrangement, pumps can be smaller, and power requirements lower. The combination of series and parallel systems join the high efficiency of series operation with the practicality of parallel design.

(b). Upflow Bed System:

The system utilizes a countercurrent principle, that is, fresh carbon is added at the top and spent carbon is withdrawn from the bottom as the wastewater enters the bottom and exits at the top. All carbon used in the treatment can be fully saturated before it is taken from the column for regeneration. In a periodically carbon discharged pulsed bed column system, the spent carbon can be easily withdrawn from the bottom of the bed by gravity or by pressurizing the column, and the carbon particles tend to maintain their relative position vertically in the bed because the specific gravity of the carbon increases from about 0.48 to 0.59 as it becomes loaded with organics in its traveling down towards the bottom of the bed due to successive withdrawals from the bottom.

Carbon columns have proven able to handle shock dissolved organics or hydraulic loads very well. Their ability to discharge a high quality effluent provides a high potential to meet the future no-discharge requirement. The dual use of the downflow bed, to remove dissolved organics as well as flocculated materials, reduces capital cost and eliminates the need of another filter or separation device. However, the economic gain by the downflow bed is offset by loss of efficiency in filtration and adsorption, and also by higher operation cost. It is possible to have the bed clogged by suspended solids in the wastewater. Since the downflow bed is basically a surface type filter, as such, it is subject to all the shortcomings of surface filters in processing sewage. Moreover, organic matter adsorbed on a carbon column may go septic; this condition produces a break-through of turbidity and organic matter. To the writer's opinion, it may be feasible to use granual carbon on a once-through, throw-away basis for on board practice.

Incineration

Incineration has been applied to destroy human and other shipboard wastes. The heat necessary for an incinerator may be developed from electricity, fuel oil, or liquified petroleum gas.

Wastes are collected in a container and subjected to sufficient heat to completely burn or destroy them. Temperature is maintained slightly above 1400 ^{o}F to prevent odors and provide a high reaction rate.

Oxygen requirements for complete combustion may be determined from a knowledge of the constituents, assuming that carbon and hydrogen are oxidized to the ultimate end products of CO_2 and H_2O. To ensure complete combustion, excess air amounting to about 50 % of the theoretical amount will be required. Raw sludge has a heat content ranging from 6500 to 9500 BTU per pound of dry solids. With adequate dewatering (to approximately 30 % solids), the process is usually self-sustaining without the need for supplemental fuel, except for initial warm up and temperature control.

Government regulations normally impose limits on noise levels, dust emissions, combustible contents in residuals, and other things. Thus the complete process of incineration will include refuse delivery, handling, burning, and air pollution control.

When properly operated, these incinerators do not produce a noxious odor or excessive smoke, and leave only a small amount of ash residue. This residue can be collected over a period of time and easily transferred ashore for proper-disposal.

An incinerator could be installed aboard almost any craft large enough to have an enclosed toilet space. Practically, the electrical model can only be utilized where sufficient power is available for proper operation. The fuel oil model is adaptable where suitable fuel oils are used for propulsion power aboard the watercraft.

The advantages of incineration are: complete prevention of pollution from human body waste; light weight device requiring minimal space. The disadvantages of the incineration are: relatively high power requirements for the electrical model; an increased fire hazard from all models; and application generally limited to human body wastes.

Biological Oxidation

Biological oxidation is one of the first treatment processes applied to the shipboard waste problem. The influent to the biological treatment plant is normally confined to human wastes flowing from the ship toilets and urinals. However, this process is also capable of handling galley wastes (after they are ground and passed through a grease trap).

The most successful biological oxidation process applied to ships is the extended aeration activated sludge process. In this system, coarse materials are screened out, organic solids ground into small particles, sewage aerated, sludge settled and returned to the aeration chamber, and the supernatant chlorinated before being discharged.

Biological treatment units may be used on large watercraft which have the capacity to carry the volume and weight requirements of this type of unit. When properly designed and operated, the system may produce secondary treatment for the sewage and may be fully comparable to an efficiently operated land-based plant. However, the system efficiency may be erratic due to the inability of the aerobic system to respond to variable hydraulic and organic loadings associated with vessel operation. Design deficiencies which make plant maintenance and operation difficult may also raise the requirement of trained personnel. In addition, the biological process may not be utilized where instant start-up is required because time is needed for development of a microbiological community which can effectively degrade organics. Although aerobic systems are generally suitable for human wastewaters and galley flows, the microbiological growth needed in the system is sensitive to flows which contain cleaning agents, grease and other compounds used on board. Because of the secondary effluent produced, in order to meet the future no-discharge requirement, the effluent demands a further polishing treatment.

CHAPTER III

STATE OF THE ART --
SHIPBOARD SEWAGE MANAGEMENT SYSTEMS

A number of shipboard sewage management systems available and/or under prototype testing are discussed in this chapter. Many of these systems were initially developed to treat the human body waste only. However, some of the systems are capable of controlling wastes from the entire sanitary system.

The commercially available systems are catagorized into three groups: the holding tank systems, biological treatment systems, and physical-chemical treatment systems. Most of the marketed devices are shown in this chapter. The systems' specification data are supplied by the manufacturers. They were collected by reviewing the returned questionnaires (see Appendix 1), prepared by the writer, from the manufacturers. The questionnaire and the manufacturers whom the writer has contacted are shown in Appendix 1 and 3 respectively.

Commercially Available Systems

Holding Tank Systems:

Holding Tank (Wilcox-Crittendent Unit)

Wilcox-Crittenden units (18) are made of white polyethylene. Each holding tank is equipped with three 1½ inch openings, one at lowest level for complete emptying and two at highest point on the ends for inlets. A 3/4 inch opening is also included for vent line. A deodorant is added to prevent odor problems and bacterial growth.

The specifications of a Wilcox-Crittenden holding tabk are presented in Table 7.

Recirculation Unit (Monogram Jet-O-Matic 160 M and Newmatic 160 MPA)

The Monogram Jet-O-Matic 160 M and Newmatic 160 MPA (19) are self-contained recirculation systems. Jet-O-Matic operates on 12 volt DC power and the Newmatic operates on air pressure hook-up. Initially, a deodorant and 8 gallons of fresh water are charged to the system. Then a filter pump allows the mixture to be filtered and recycled after the flush. Materials for construction are stainless steel, fiberglass and high impact plastic components. The electric, push-button operated, Jet-O-matic may be converted to 110 volt AC by using a converter. The push-button, air-operated Newmatic requires about 1/3 cubic foot of air at 10 psi for each 10 second flush.

The specifications of Jet-O-Matic 160 M and Newmatic 160 MPA are presented in Table 7.

Portable Holding Tank (Thetford Sea Farer, Porta Potti) (20)

Thetford's Sea Farer is a compact self-contained portable sanitation device designed specially for V Bunk installation. The Sea Farer comes as one unit which is divided into two storage chambers. The top chamber stores 2 gallons of fresh water for flushing, the bottom chamber is the waste holding tank with a 4 gallon capacity. The two chambers are separated and sealed from each other by a gas-tight, odor-tight seal. This seal is opened momentarily during flushing. A controlled water level device matches the fresh water capacity with the holding tank capacity, thus no extra water is left in the unit when evacuation is required. To evaculate the Sea Farer, the unit is carried to any permanent toilet facilities. Then, remove the cap which seals the holding tank chamber and pour tank contents into the permanent toilet.

A similar model is Porta Potti.

The specifications of both the Sea Farer and Porta Potti are presented in Table 7.

Vacuum Flush Unit (Mansfield VACU - FLUSH)

Mansfield VACU-FLUSH (21) is designed to meet the goal of a marine toilet system with extremly low water usage. Figure 4 shows a typical system layout.

A complete pump-thru VACU-FLUSH system may consist of up to 6 Mansfield 200 series vacuum toilets; a vacuum sewage pump with an accumulator/separator tank and inlet-discharge fittings; a control panel; air control hardware; and wiring.

As the vacuum pump runs, a vacuum is created in the pump accumulator tank, system lines, and toilet base. As this vacuum reaches 10 inches of mercury, a pressure switch in the control box will close, turning on the green READY light at each toilet. The toilet may be flushed anytime after this light comes on.

When the toilet is flushed, the contents arepulled into the base by the surrounding air rushing to fill the system vacuum. The sewage then travels through the system lines at a velocity of 20 ft. per second until the vacuum is exhausted.

When the sewage reaches the pump accumulator tank, it falls to the tank bottom. The next time the pump is cycled, the sewage is pulled into the pump inlet and is discharged under pressure at the pump outlet. Sewage may then be moved to any desired location under pressure.

With the proper valving, this same pump may be used to pump the contents of an on-board holding tank overboard in unrestricted waters.

The specifications of a VACU-FLUSH are presented in Table 7.

Recirculation Tank (Thetford Electra Magic)

Thetford's Electra Magic recirculating toilet (20) system is a self-contained sanitation system which does not require a pressure connection. The water supply and holding tank components occupy the same area. Flush water is pumped through a filter, then into the bowl component. Flush water and waste then return to the water supply and holding tank area.

The holding tank is evacuated by gravity flow or by pumping the contents into a permanent disposal facility. A deodorant is added to the system to eliminate any odor problem and bacterial growth.

On the front of the Electra Magic, a prismatic level indicator is installed. It measures the level of the storage tank contents, the correct charge level, and indicates when to evacuate.

The specifications of an Electra Magic are presented in Table 7.

Holding Tank (Aquatic-Designs Marine Waste Holding Tank)

Aquatic-Designs marine waste holding tanks (22) are developed to apply to recreational watercraft. Models No. 30 and No. 20 are available. Based on one quart per flush, model 30 is good for 120 flushes and model can handle 80 flushes. Both models include one dock side discharge service fitting, two through-hull vent fittings, four 1½ inch stainless steel clamps, four 3/4 inch stainless steel clamps, positioning straps and fittings. Specifications of an Aquatic-Designs system are presented in Table 7.

Recirculation Unit (Vapor Corp's Unit)

A vapor unit (23) is a completely self-contained toilet which utilizes the recirculation principle and has a usable capacity of 8 gallons.

All of the waste material is held in the tank; and when it reaches the level at which the toilet has to be serviced, the contents are removed by opening a drain valve and directing it into a service cart or into a sewer.

The unit contains a pneumatically operated pump which provides a 10-second flushing period when the flush valve is depressed, the flush valve being a self-completing type of valve and having an integrally-built pressure regulator to reduce line pressure from 20 to 150 psi to the proper operating pressure for the pneumatic diaphragm type pump. The pump is equipped with a multiple pin filter to prevent solids from working their way into the pump.

The drain valve is a slide type valve, located at the bottom of the tank and which is normally piped to a drain line for easy access to permit removal of waste as indicated above.

A water fitting with a spray nozzle is incorporated to permit flushing of the toilet at time of servicing from a water pressure line of up to 40 psi.

The toilet is normally precharged with 3 gallons of water, a chemical-bacterial retardant, and blue dye for esthetic purposes.

Portable Toilet (Potpourri)

Potpourri is a self-contained recirculation toilet system (24). Units are available in model 707 for 4 people with 3 days usage and model 737 for 4 men and 6 days usage. Initially, 1½ to 2 gallons of fresh water are flushed into the holding compartment with a biocide. A pump assembly is so arranged that in pumping water back into the bowl for each use, it is automatically filtered.

The specifications of Potpourri are presented in Table 7.

Holding Tank (Jonny Trap)

Jonny Trap is of fiberglass, corrosive-free construction. The capacity is available from 12 gallons to 42 gallons (25). Each assembly consists of a holding tank, sewage inlet fittings, through-hull vent fitting, and deck fitting for a deck side pump connector. The specifications of Jonny Trap systems are presented in Table 7.

Recirculation Toilet (Jensen's Models)

The Jensen recirculation-holding tanks are molded of ABS plastic with stainless steel metal components (26). A deodorant is added to prevent odors and bacterial activity. A pump assembly is arranged so that in pumping water back into the bowl for each use, it is automatically filtered. The capacity can be up to 80 flushes.

The specifications of Jensen's systems are presented in Table 7.

Recirculation Tank (Kracor Systems)

Kracor systems are recirculation holding tanks equipped with a cylindrical screen, sewage port, recirculating port, vent, back-flush hose connection, waste drain connection, two level control probes and a visual condition indicator post located in the top of the tank (27). Tank walls are molded of linear polyethylene. Capacities are available from 6 gallons to 25 gallons.

Initially, suitable amount of fresh water is charged into the tank with a deodorant. When pumping water back into the bowl for each use, it is automatically filtered.

The specifications of Kracor systems are presented in Table 7.

Recirculating Toilet (Craft Mobil Toilet)

The Craft toilet (28) is designed for the average family with 4 to 6 days usage. At the begining 3½ gallons of fresh water and biocide are added to the 9 gallon capacity tank. Body wastes are macerated by a macerator which is installed inside the 9 gallon tank. An air vent to the exteior, one outlet for dockside pump out, and an outlet for self-evacuating to holding tank or sanitary sewer are also provided.

Biological Treatment Systems:

Biooxidation Unit (Bio-Pure)

The Bio-Pure system (29) is designed for seagoing barges andships. It utilizes the concepts of disintegration, aeration, clarification, and chlorination. The process is shown in Figure 5.

All of the ship's sanitary wastes pass through a disintegrator basket to break down the particle size. The disintegrator basket is constructed of mesh wire. Turbulence caused by the aeration mixing pump agitates the basket and results in attrition of all degradable solids which enter the system.

After passing through the disintegrator, sewage is aerated. The aeration chamber provides a surge tank for variable influent flow rate. The aeration chamber remains at least one-fourth full in order to provide a basic colony of bacteria for digestion of fresh influent during the standby period. Aeration takes place on an intermittent cycle by injecting air through a venturi.

It thus continues on an intermittent basis until the aeration chamber becomes approximately two-third full. At that level, a float switch starts the timer, which in turn starts the mixed liquor transfer pump. A controlled volume of liquor is then transferred to the clarifier where settling takes place during the timed cycle. During the settling cycle in the circulation stage, the aeration pump or pumps run continuously to aerate the next batch. The submerged pumps transfer heat to the surrounding liquid in the aeration chamber, thereby increasing the biooxidation rate.

When the mixed liquor transfer pump transfers a controlled volume to the clarifier, the cycle continues to a weiring level whereby all floating materials pass over the skimming weir back to the aeration chamber. After the mixed liquor transfer pump cycle is completed, the batch of mixed liquor is held for a controlled period of in the clarifier. At the end of the settling period, approximately one-third of the clarifier volume is transferred by the supernatant transfer pump on a time-controlled cycle through the chlorinator, to the chlorine contact chamber. The remaining liquid and sludge is returned to the aeration chamber by the sludge return pump. At the end of this cycle the clarifier is empty and ready to receive another batch of mixed liquor from the aeration chamber.

When the supernatant transfer pump transfers a controlled volume of clarified liquor to the chlorine contact chamber, the liquor is forced through a simple contact type of chlorinator. This chlorinator allows the supernatant liquor at a controlled rate to contact chlorine tablets. After the transfer cycle is completed, the batch of chlorinated supernatant is held for a controlled period in the chlorine contact chamber. At the end of the fixed contact time, approximately ninety percent of the chlorine contact chamber volume is pumped out to disposal by the discharge pump on a controlled cycle. The remaining liquor, as well as any settled material that may collect at the bottom of the chlorine contact chamber, is returned to the aeration chamber by the returned pump. The tank is thus pumped empty and can be washed for cleaning as required. The specifications of a Bio-Pure system are presented in Table 7.

Biooxidation-Disinfection Unit (Red Fox Marine Sewage Unit)

The Red Fox RF 3000 M Sewage Treatment Plant (30) is designed to treat all of the ship's sanitary wastes by using extended aeration and disinfection concepts. Raw sewage passes through a comminutor and a screen prior to entering the aeration chamber. Effluent from the aeration chamber is then subjected to a settling tank for clarification. Clear liquid is chlorinated before discharge and settled sludge is returned to the aeration chamber. Figure 6 shows the system schematic diagram.

A comminutor is equipped inside the aeration chamber to reduce solid particles to ¼ inch or smaller. Air is introduced into the aeration chamber by means of diffuser system supplied with air from a positive displacement blower. This air serves a two fold purpose . It imparts the required amount ofoxygen for biooxidation and also provides agitation to insure mixing of the tank contents. Heat is supplied externally to the aeration chamber to increase the reaction rate.

The settling chamber is baffled and the bio-floc settles only by gravity. From the clarifier the aerated liquid flows through the effluent manifold into a chlorine contact chamber where it is treated by an injected sodium or calcium hypochlorite solution from the solution chamber. Injection is accomplished by means of a variable stroke diaphragm injection pump. From the chlorine contact chamber the effluent flows into the effluent tank which is provided with a flanged connection for either gravity discharge overboard or discharge through effluent pumps.

The specifications of a R d Fox system are presented in Table 7.

Biooxidation Unit (Demco Waste Treatment Process)

The Demco system (31) is designed to treat all of the sanitary wastes from a ship by applying the extended aeration concept. Capacity is available from 325 gpd to 12,500 gpd.

Selective bacterial-enzyme mixtures are added periodically to encourage the biooxidation reaction rate. Extended aeration is provided in three stages. Final disinfection of the effluent is accomplished by adsorption of chlorine from dry soluble calcium hypochlorite tablets in the contact chamber. The system schematic is shown in Figure 7.

Raw sewage enters the system by gravity , and is directed into a digestive reducer basket located in the first aeration compartment where the solids are subjected to hydraulic maceration and then pass through a ¼ inch mesh screen into the aeration chamber. A mechanical enzyme feeder mounted on the top of the tank adds the bacterial-enzyme at a rate of 1 to 2 ounces per day into the first aeration chamber. The feeder has a capacity of approximately one-pound , suitable for 2-3 weeks operation prior to refilling.

Aeration is provided by a positive displacement blower located on the top of the tank and belt-driven by an electric motor. Air is distributed at 4-5 psi through galvanized piping into a diffuser located near the bottom of the three aeration chambers and at the base of the digestive reducer basket. The diffusers divert air bubbles into the chambers to provide agitation and oxygen supply for the biooxidation . The minimum aeration time in the three compartments is 16 hours. The specifications of a Demco system are presented in Table 7.

Biooxidation Unit (Weldco System)

The Weldco system (32) utilizes biooxidation and sedimentation principles to remove dissolved and suspended solids from the water. A system schematic is shown in Figure 8.

A comminutor is mounted on the top of the aeration chamber. Raw sewage enters the comminutor and the solids contents are broken down to smaller size by the shear action of the blades. Pulverized sewage then travels to the aeration tank where air diffusers constantly keep the liquor agitated. Effluent from the aeration tank passes over a weir into the settling tank where settlable solids are removed by gravity. Clear liquid then flows over a weir into the chlorination tank.

Settled sludge is pumped into the re-aeration tank where it is mixed with activated sludge. A portion of this mixture is transferred to the chlorine tank and pumped overboard to prevent sludge build up. Treated sludge then enters the aeration tank where it mixed with raw incoming sewage and the entire process is repeated.

The specifications of a Weldco system are presented in Table 7.

Biooxidation-Flotation Unit (IWC System)

The IWC system (33) is designed to treat all of the sanitary wastes from a ship. It utilizes a combination of biooxidation, flotation, sedimentation, and chlorination to remove pollutants from liquid water. Systems are available at capacity of 500, 1500, 5000, and 10000gpd. A schematic diagram is shown in Figure 9.

A comminutor equipped inside a surge tank reduces the solids into a uniform phase. A cutter type feed pump delivers the sewage at a constant flow rate from the surge tank to the process pump which in turn recycles and delivers sewage to the oxidation tank via the air entrainment device. In the oxidation tank the sewage is oxidated and separated. The thicker liquor is returned to the process pump, while the lighter liquid is transferred to the flotation tank under pressure. The sudden expansion from the oxidation tank into the flotation tank induces flotation. A skimmer device in the flotation tank returns the flotables to the process pump and the heavier liquid settles to the bottom of the tank where they are also returned to the process pump. The clearer liquid is transferred to the settling tank.

The liquid enters the settling tank from the flotation tank to accomplish further settling in a quieter atmosphere. The settling tank also has a skimmer device which returns any flotables to the process pump through the tank bottom connection. The effluent from the settling tank is then transferred to the effluent holding tank where the transferred liquid is chlorinated and discharged,

In order to remove excessively accumulated sludge, on a weekly basis, 5 gallons of liquor are drained from each of oxidation tank, flotation tank, and settling tank. In the drain-off liquor, the liquid portion is poured back into the system's surge tank and the remaining solids are disposed of as solids waste. The specifications of an IWC system are presented in Table 7.

Biooxidation Unit (Bio-Flo)

The Bio-Flo system (34) combines mechanisms of biooxidation, adsorption, filtration, and chlorination in a compact polyplastic bag. It is designed to treat human body waste only and each system is equipped with one head.

The system can be divided into three phases: liquid enzyme phase, "Bio-Bed" phase, and chlorination phase. Sewage flows into the liquid enzyme phase where the major removal of organic matters takes place. The digested liquid then passes through the

"Bio-Bed" phase where dissolved solids are further removed by adsorption. Effluent from the "Bio-Bed" is treated with chlorine prior to discharge.

In the liquid enzyme phase, a combination of fat, carbohydrate, protein, and cellulose-digesting enzymes, aerobic and anaerobic bacteria, and surfactants incorporated in tablet or powder form are added weekly. The highly active catalized reaction rate shortens the requirement of a long retention time in the conventional biooxidation process.

A down-flow type activated carbon column is used. Bacteria can establish on the extensive surface area provided by activated carbon. As a result, adsorption, filtration, and biooxidation can be accomplished in this stage.

Biooxidation-Chlorination Unit (Microphore M-10, M-12)

Microphore systems (35) are designed to utilize wood bark as filtering media and biological digestion supporting material. Sewage matter flows through the bark where waste particles cling to it. This action absorbs oxygen for the use of microbes that carry on community life in the openings of the bark fibers. The process takes place in a digestor unit. The reduction process takes place over a long period of time. Effluent from the digestor is chlorinated by adding chlorine tablets.

The specifications of Microphore systems are shown in Table 7.

Physical-Chemical Treatment Systems:

Vacuum Flush Incineration Unit (Jered VACU-BURN)

The Jerd VACU-BURN sewage disposal system (36) combines the principles of vacuum flush and incineration. It is designed to treat the human body waste from toilets and urinals. The sewage mass is carried through the lines under differential air pressure between the system and atmosphere. A centralized vacuum collection tank is utilized to store the sewage. Tank contents are macerated and metered to an incinerator. The incinerator burns and reduces the sewage to inorganic ash and flue gases. Ash is disposed of ashore. An alternativeis also provided to pump overboard the ground sewage in unrestricted waters. Figure 10 shows the system schematic.

The system is composed of two distinct elements, namely, collection and treatment. Collection includes the special toilets of the limited volume flush type, the sewage lines, the vacuum pumps and the central vacuum collection tank. Treatment is achieved by incineration of all waste collected. The water closets are standard size and are external conventional appearance with electro-vacuum operated, flush-controlling, interior valving. The operation of a water closet flush lasts four seconds, and deposits two pints of flushing water. Two liquid-ring type of vacuum pumps are operated to keep the system under the desirable range of vacuum. The pumps are supplied with water from a 50-gallon reservoir. The units are mounted on the top of the reservoir. The vacuum is kept between 14 and 20 inches of mercury.

The vacuum collection tank is partitioned into two halves, with a combined total volume of 240 gallons and a useful liquid volume of 224 gallons. Three 2-inch diameter lines from the toilets discharge into the coarse side of the collection tank. The sewage is then processed through the pump grinder and transferred to the fine side of the vacuum collection tank. The sewage is then transported to the incinerator or dumped overboard depending on whether in restricted or unrestricted waters.

A pump grinder is vertically mounted with the inlet to the grinder below the bottom of the vacuum collection tank.

The incinerator burns macerated human sewage diluted in fresh water or sea water. The liquid sewage is sprayed into the combustion chamber for complete combustion. The vortex type combustion chamber is fired by tangentially-mounted burners. A centrifugal blower supplies combustion air and cooling air. The air supply for atomizing the sludge is made available from the ship's compressed air supply.

The specifications of a Jered VACU-BURN system are presented in Table 7.

Recirculation Oil Flush Unit (Chrysler Aqua-Sans Systems)

The Chrysler Aqua-Sans systems (37) are designed to use oil as the flushing medium. The density of the oil is some 17 % less than that of human waste, permitting gravity separation. It is immiscible with the waste and chemically stable under the operating conditions and in the presence of human waste.

The human waste is received in a standard commode, flushed with the oil to the separation tank where it is separated and from which it is transferred to a waste collector. A two-stage incinerator renders the waste into an acceptable condition for disposal. The separated oil is filtered, lightly chlorinated. and returned to the heads. Four models are available for capacities at 600 gpd, 1500 gpd, 5000 gpd, and 10000 gpd. A system schematic is shown in Figure 11.

Waste is transferred by the flush liquid from the commodes to the separation tank where the solids are separated and settled in the sump while the flush fluid rises to the top due to the differences in density of oil and waste. The flush fluid rises, passing through a coalescer which remove entrained urine, and then flows over a weir through a bag filter into the second stage tank.

Flush fluid is recirculated to the commode by a pressure pump which is activated by a pressure switch. A bladder type accumulator is provided to prevent surges and to meet peak flow condition.

Fluid gravity is maintained by circulating the flush fluid through a pre-filter, an activated carbon column, and a clay filter. These units remove fine particles and dissolved contaminants such as lipids, surface active agents, color bodies, and some odor producing contaminants. Bacteria and odor are controlled by the periodic addition of chlorine compounds to the flush fluid.

When sufficient waste accumulates in the sump, it is detected by a waste sensor. This activates the macerator pump which transports the waste to the waste holding tank. The dump switch actuates when the waste holding tank is half full and initiates incinerator warm up. Waste transfer, start, stop, and incinerator shut down are controlled automatically.

The specifications of Aqua-Sans are presented in Table 7.

Electrolysis-Incineration Unit (Colt's System)

The Colt's system (38) allows the sewage to pass into an interceptor which removes the coarse solids and then to a transfer unit. The fine solids are proceeded to an aerated holding tank with liquid where the waste load and flow surges are balanced, Liquid is then pumped from the holding tank to the chlorinator where the residual suspended solids are floated and removed to the transfer unit, while the liquid remaining in the chloroflotator is chlorinated. The treated effluent from the chloroflotator flows to a sump tank and is pumped overboard. The solids that are collected in the transfer unit activate a sensor at a predetermined level of accumulation, whereby they are transferred to the incinerator and destroyed on a programmed cycle. Figure 12 shows a system schematic.

A pacer is installed at the entrance of the interceptor. The pacer is a continuous operating gate device which limits the maximum flow of sewage from the ship piping into the sewage unit. The interceptor consists of a multiple disc three drum continuously cleaned rotating bar screen which separates coarse solids from waste water.

Liquids which get into the transfer unit from the interceptor and chloroflotator, drain into the transfer device drain tank where they are pumped into the holding tank. This pump operates continuously and can run dry.

The liquids and coarse solids are pumped, upon high level signal, from the holding tank into the chloroflotator. A chemicalsolution is pumped into the chloroflotator from the hypochlorite system to disinfect the liquid. The energized electrodes in the chloroflotator generate chlorine by electrolysis. The generated gas bubbles rise to the top of the chloroflotator carrying with them the small suspended particulate solids. Flotated solids are skimmed mechanically into the transfer device. The liquids are disinfected through an overflow weir.

The specifications of a Colt's electrolysis-incineration system are presented in Table 7.

Filtration-Incineration Unit (Thiokol MPB-10)

Thiokol's system (39) obtains a high quality effluent by using filtration to take away suspended solids, catalytic oxidation to remove dissolved solids, chlorination to destroy bacterial growth, and incineration to completely convert the suspended organic solids into inert ash. The system is designed to treat all of a ship's sanitary wastes for a crew capacity of 10. The whole reaction requires 20 minutes or less. Figure 13 shows the system schematic.

A 15 gallon primary holding tank with level indicator and suitable alarm is utilized to receive the flush. Hypochlorite is added to the tank for odor control and bacteria activity control from a chemical additive dispenser which is mounted on the top of the tank. When sufficient sewage has been collected, the filtering cycle is started. As a suitable alarm is activated by the level indicator. The operator then transfers the waste materials from the holding tank to the filter bed by means of a manual or motor operated pump. The waste material passes through the filter bed and enters the baffled secondary holding tank. The suspended solids are removed by the filtering action. This operation requires about five minutes.

The operator then initiates the dissolved solids treatment by starting a small pump that continuously recirculates the effluent through the catalytic reactor and back to the secondary holding tank. At the same time, the incinerator begins to dispose of the suspended solids collected in the filter bed. Incineration takes about 30 minutes; after that, the treated material in the secondary holding tank is pumped overboard and filter bed is allowed to cool. Liquid from the flush water source can be used to backwash the small amount of ash left on the filter element. The system is ready to accept the next batch of material approximately 1 hour after the previous batch has been treated.

The specifications are presented in Table 7.

Centrifuging-Oxidation-Incineration Unit (Thiokol's Non-biological Waste Treatment System)

This Thiokol system (40) removes coarse solids from the sewage with a hydrausieve. The influent is discharged into the trap which utilizes a 1-inch mesh screen to remove large solids. Foreign objects including metallic materials and glass are held in the trap for manual removal. The remaining large solids are macerated and recycled while liquid and small solid particles are transferred to the holding tank. An automatically discharging, basket-type, centrifuge concentrates the residual solids to a slurry. The solids are deposited on the walls of the centrifuge basket where they are periodically removed by the skimmer and fed to the slurry tank. The coarse solids and slurry are oxidized in an incinerator. The concentrated solids are sprayed onto the incinerator and completely destroyed.

The fluid coming from the centrifuge is first chlorinated in electrolysis cells, and then passes through catalyst column. In these columns, the reaction between the oxidant and the residual organic matter carried by the fluid is accelerated. The system is designed for 200-man crew with a total waste volume of 6000 gpd. The effluent water has a clear appearance with a slight milky turbidity, foaming, and a dilute bleach solution odor during flush. Figure 14 shows a system schematic diagram and Figure 15 is a schematic of a modified no-discharge system.

Screening-Ultrafiltration Unit (Lundy UF-5)

The Lundy system (41) is a continuous flow operation, consisting of three basic steps: (a) screening, (b) ultrafiltration, (c) solids storage. It is designed to treat all of a ship's sanitary wastes. The incoming sewage is received by a 150-gallon surge tank. A process pump constantly brings the sewage from the bottom of the surge tank to the surface of a vibrating screen. Coarse solids are caught and removed to a solids holding tank, while the filtrate is transferred to another 300 gallon storage tank. Liquid in the secondary surge tank is then pressurized to a suitable pressure (up to 600 psi) through an ultrafilter. An automatically regulated recycle line allows the flow rate to the menbrane filter to remain constant. Solids sizing from 10 A up are retained on the concentrate side of the filter. The effluent from this ultrafilter has very high quality.

The concentrate is then mixed with a polyelectrolyte and ferrous chloride. The resultant floc is allowed to settle by gravity in a settler. Settled solids are pumped to the solids holding tank while the clear liquid is brought back to the 300 gallon storage tank.

The specifications of a Lundy UF-5 are presented in Table 7. Figure 16 shows a system schematic.

Incineration Toilet (Ocean System Inc. Unit)

The Ocean System Inc. unit (61) is an incineration toilet that uses a store and burn principle. The toilet bowl has an arrangement for allowing wastes to fall into the combustion chamber. Closing the lid after a usage activates the flap, dropping the contents of the bowl into the combustion chamber. Wastes are stored for a suitable period of time (typically 24 hours) and then incinerated. In most cases the wastes would be stored all day and then incinerated at night. The wastes are incinerated at a high tempertare (2100 ^{o}F), thus eliminating odors from the burning process. The combustion chamber is designed to hold the wastes from 30 to 50 uses (both urinations and defecations). The mass of ash remaining after each incineration is approximately 2 % of the pre-incineration mass, so the chamber can be operated forseveral weeks before it becomes necessary to empty the ash residual.

Figure 17 shows the system schematic. The specifications of an Ocean System Inc. incineration toilet are presented in Table 7.

Adsorption-Incineration UNit (Westinghouse System)

The Westinghouse system (42) is designed to treat only human body waste and is housed in approximately the same volume as a conventional commode. The system removes solids waste from the liquid, incinerates the solids, and purifies the liquid for reuse. A system schematic is shown in Figure 18.

Wastes are introduced into the toilet bowl and the flush button depressed to initiate the treatment cycle. Depressing the flush button mechanically rises a ball which allows all water and waste contained in the bowl to flow out and start the flush pump. The flush pump supplies a flow of sterile, treated water to cleanse and refill the bowl. Thirty seconds are required for flushing.

The waste from the bowl falls onto a conveyor of tightly coiled springs. The liquid flows between and through the springs into a sump. Any solids larger than approximately 20 mesh in the waste are retained on the springs and conveyed to the incinerator.

The liquid is accumulated in the sump until required for further flushing. On the next flush cycle the flush pump removes water from the sump and passes through a filter filled with activated carbon. The carbon filter removes small colloidal particles not removed by the springs and adsorbed contaminants dissolved in the water.

After the water is filtered, it is sterilized by the addition of chlorine from calcium hypochlorite tablets. This purified, sterile liquid washes and refilles the toilet bowl for the next use.

Once each day, any solid material that has accumulated in the incinerator is burned. The burn cycle is initiated by closing the incinerator door and setting the timer. Incineration is completed in about one hour. The system can be used over two-hundred times without the need for liquid discharge.

The specifications of a Westinghouse system are presented in Table 7.

Interception-Recirculation-Incineration Unit (Koehler-Dayton MSTS)

The Koehler-Dayton (43) has been designed to treat all of the ship's sanitary wastes by using the recirculation, disinfection, interception, and incineration concepts. Discharges from the heads and wash stands are collected and screened before recirculation. Concentrated wastes are then converted to a storage tank. Upon activation by an integral control system, the waste matter is transferred to a thermal chamber where complete destruction of the waste is completed. Figure 19 shows the system schematic.

Two recirculating tanks mounted on the top of storage tank are utilized to intercept all of the discharges from shipboard sanitary systems. Each tank is equipped with a static type filter which separates solid waste from the liquid. The liquid is recirculated along with prime water in which a 6 % paraformaldehyde base chemical is added automatically on a daily basis to preclude potential odor. The treated solution is then recirculated to the urinals and water closet bowls. The solution also serves as a wetting agent to help clean the water closet bowls.

One of the recirculating tanks is the recipient of all the drain water (sinks, showers, etc.) and as a result, fills at a much higher rate than the first tank. Both tanks are automatically switched into operation when the second tank is approximately 50 % full. The second tank then becomes the receiver of all the waste from the water closet bowls and urinals and all the waste in the first tank is transferred to the surge tank by means of gravity flow. The surge tank allows for intermediate retention of sewage prior to reduction. The waste in the collection tank is automatically metered into the thermal chamber in which it is reduced to a sterile inert ash.

The thermal chamber is operated between 1600 ^{o}F and 1700 ^{o}F and uses the same type fuel which is used in the vessel's main propulsion system to completely destroy the waste. Odor is eliminated under this range of temperature. The exhaust stack from the thermal chamber is led to the main exhaust system of the vessel. The waste reduction unit is equipped with its own control panel and special devices which are designed to regulate the exhaust temperature and assure complete combustion and the elimination of odors. Ash residual are removed by conventional means.

The specifications of a Koehler-Dayton MSTS system are presented in Table 7.

Separation-Recirculation Unit (Seapax System)

Seapax systems (44) are chemically-treated recirculating types, and are designed to accept human body waste only. Sewage passes through a separation tank prior to a main settling tank where escaped solids from the separation tank tend to settle by gravity. A bar screen is equipped in the separation tank to remove coarse solids.

A pump-grinder transfers the screened sewage into the settling tank with a uniform solid particle size distribution. A filter screen is located at the suction end of the settling tank. It allows clear liquid be pumped through a pressure pump into a pressure tank where the storage water is utilized directly as flush water.

An overflow well is provided to permit excess water in the settling tank to flow into the holding tank. Solids are periodically transferred to the holding tank through a recirculating pump. The input load to the holding tank is estimated at ½ gallon per person per day. Systems are so designed that sea water flushing of vessel's sanitary service is allowed while the vessel is in unrestricted waters. A system schematic is shown in Figure 20.

Before the system is placed in operation, it is first primed with the required amount of fresh or salt water to the working level of the main tank, and the pressure tank is charged to the proper cut-in/cut-out pressure. Caustic alkalinity and trichloroisocyanurate are then added and allowed to circulate through the system for several hours, after which time alkalinity in the system is measured. When the alkalinity reading is within a preselected range the plant is ready to receive raw sewage. The sterilizing function then occurs all over the system.

The specifications of Seapax system are presented in Table 7.

Disinfection-Filtration Unit (FMC Marine Sanitation Device)

The FMC system (45) has been developed to receive sewage from flush water, showers, basins, laundry, and galley. After processing, the effluent can be discharged overboard or recycled to an interim holding tank for reuse. Models are available for 4000, 8000, and 50000 gallons per day flow capacity.

The combined sewage flows into a macerator-strainer with a controlled amount of bactericide. Upon activation by an integral control system, the partially treated waste matter is macerated and pumped to the following surge tank. Dry chemicals are added to encourage the filtability of sewage. Effluent from the surge tank is then mixed with coagulants prior to filtration. Figure 21 shows the system schematic.

A macerator-strainer housed in a 9-gallon cylindrical tank, with the strainer removable from the tank, is utilized to reduce the particle size to one-half inch or smaller so that they can move freely through the system. Chlorine is stored in a 30-gallon cylindrical polyethylene tank. A predetermined amount of chlorine is pumped automatically to the macerator-strainer tank upon receipt of a signal from a flow sensor installed in the waste line. A 64-gallon surge tank with a motor-driven agitator is designed to handle the load fluctuations and to promote uniformity in the distribution of solid particles and dry chemicals from the dry chemical feeder.

The dry chemical feeder system is a steel hopper with a vibrator and a vibrating chemical metering feeder mounted on the surge tank. A mixture of powdered activated carbon and Johns-Manville "Celite" filter-aid are fed to the surge tank. Dry chemicals are added automatically, and in certain proportions by a vibrating feed mechanism.

As the surge tank fills, sewage is moved by a low volume pump, and alum is introduced automatically to condition the sewage as it flows through a copper-nickel pipe reactor coiled around the surge tank.

Treated sewage then flows to the pan of a rotary vacuum filter system. Here, liquid and solids are separated. The specifications of a FMC system are presented in Table 7.

<u>Filtration-Incineration Unit</u> <u>(Hyde Waste Treatment System)</u>

The Hyde system (46) utilizes chemical treatment, filtration, and one of several methods of sludge disposal to treat all of the sanitary waste from a ship.

The system collects the sewage in the main tank, comminutes it to fine particles, treats it with a sterilizing chemical and also with sludge conditioning and pH control chemicals, and then filters the solids from the sewage using an automatic backwashing deep-bed three dimension filter. The effluent produced is discharged overboard or used as raw water for boiler make-up water. The sludge is handled either by direct combustion in the boiler fire-box, incineration in a separated liquid incinerator, dewatering by various methods and then combustion in a standard trash incinerator, or containment aboard and disposal ashore.

A system schematic is shown in Figure 22.

Two chemicals,contained in plastic lined steel tanks, are added to the main collection tank. One sterilizes the sewage and controls the pH while the other chemical isa sludge conditioning chemical which improves the physical characteristics ofthe solids in the sewage to make them more easily filtered and handled. Two positive displacement diaphragm pumps are used to feed the chemicals into the collection tanks.

A comminutor is mounted on the top of the collection tank. It grinds the solids into a more homogeneous phase. An overboard discharge pipe line is installed close to the tank to discharge the raw sewage in unrestricted waters.

The main collection tank has a volume of about 900-1200 gallons. A two section tank is used with a partial bulkhead between the sections so that larger, heavier particles will tend to be recirculated through the comminutor. Single paddles, which come to within one inch of the tank bottom, are used to agitate the tank and are driven by a worm gear motor at 35 rpm.

The recirculation of the sewage from the first compartment through the comminutor eventually reduces all the solids to size which will be acceptable to the filters. The recirculation is required to avoid shutting down and restarting the filters.

The filtration unit is controlled automatically. In the filter cycle, sewage from the holding tank enters the filter through the filter feed pump. It passes downward through the primary filter where the larger solids are removed and entrained in the granular media. The water is then passed in the same manner through the secondary filter where the remaining solids are removed. When either filter is fully loaded and the pressure drop exceeds 15 psi, the filter will automatically shift to the backwash mode.

The backwach cycle is controlled by a cam programmer timer for each filter. The separation of contaminants from the media is accomplished by pumping the dirt laden media with the scrubber pump through a scrubber tube where turbulent flow causes the separation of the contaminants from the media. The water from the system is used to backwash the filter. The clean media is returned by the scrubber pump to the filter. The backwash cycle is proceeded by a short agitation period before the backwash discharge valve is opened. The purge cycle resets the filter bed recirculating sewage through the system. When the purge cycle is complete, the filter automatically returns to the filter cycle.

A flat-bed type consumable media filter is used for drying the sludge. The unit is totally enclosed and built for the shipboard environment. This filter allows the water to drain by gravity back to the main tank while the solids are retained on a papercloth media. The media is indexed automatically after a predetermined period by a timer. The media and dry solids eventually drop into a container and are periodically carried away to a standard marine trash incinerator for consumption.

The specifications of a Hyde system are presented in Table 7.

Electro-Coagulation Unit (General Electric SWTS)

The General Electric Shipboard Waste Treatment System (SWTS) (47) has been designed and developed to treat all of the sanitary wastes from a ship. The SWTS system comminutes the influent sewage solids, electrically generates a coagulant, flocculates and separates the solids to form a sludge, incinerates the sludge, and clarifies and disinfects the effluent water to discharge or reuse. Figure 23 is a schematic diagram of the SWTS system.

The pump grinder is mounted on a sewage holding tank which is sized with sufficient volume to accept the peak loads and equalize the operating cycles of the system to allow a constant rate process. The pump grinder is installed to a depth within two inches of the tank bottom. This clearance, which is accessible from a special access port, provides sufficient volume for metallic objects to settle out harmlessly.

The electro-coagulation cell is an electro-chemical purifier which generates the ferrous hydroxide coagulant,in the presence of sewage solids electrically to flocculate suspended solids and reduce bacteria and BOD. The electrocoagulation cell is a wholly sealed unit. A downcomer mixes the coagulated wastes with a flocculant aid. The clarifier separates the suspended solids from the liquid by forming a sludge blanket. The sludge concentrator provides final agglomeration and sludge concentration. The sludge holding tank accumulates sufficient sludge to keep the incinerator burning for a minimum period of one hour. The incinerator system, which consists of a commercial burner unit fired with diesel oil, an air-cooled vortex type combustion chamber with tangentially injected flame, and a motor driven fan and fuel pump, vaporizes the sludge and completely incinerates all sludge solids.

The chlorinator is used to reduce the supernatant bacterial content to a harmless level. The G.E. SWTS system utilizes a maceration and electrocoagulation treatment process. A 150-gallon sewage holding tank is provided to smooth the sewage load to allow a constant flow rate process. This assures that all influent sewage is always exposed to equal treatment. Air is supplied to this tank to maintain the aerobic conditions necessary for treatment effectiveness. When a predetermined quantity of influent sewage is in the holding tank, the pump grinder is activated by the level sensors. The influent solids are then ground and pumped at a rate of five gallon per minute to a coagulation cell.

The coagulation cell consists of mild steel plates in a parallel matrix within a housing such that all waste water flow must traverse the space between the plates. A controlled,direct current voltage is applied to alternative plates. The reactions which occur include the release of ferrous ions from the anodes and the electrolysis of the the waste water flowing in the plate spaces. An automatic, timer-operated, air-scrubbing system is provided to periodically clean the sludge which may accumulate on the plate. The air and the hydrogen generated are vented overboard.

The floc formed in a cell is passed through the downcomer, where it is mixed with sodium aluminate flocculant aid and gently agitated to enhance agglomeration and facilitate formation of a sludge blanket. The sludge blanket serves as a filter for suspended solids and possibly an adsorber of dissolved BOD. The discharged liquor is of high clarity when the clarifier flow rate and sludge settling rate are maintained in equilibrium.

The sludge is drawn off from the solids separator and discharged into the sludge concentrator, where it is further concentrated prior to storage in the aerated sludge holding tank. When a sufficient amount of sludge has been accumulated, sludge has been accumulated, sludge is withdrawn from the tank for incineration.

The incinerator has a capacity of 4000 pounds per day of liquified sludge consisting of 90% to 100% liquid and 0 to 10% solids by weight. The sludge is sprayed into the incinerator and entrained in the vortex until complete combustion is achieved.

The liquid portion is vaporized , and the vapors are heated to ensure an odorless exhaust. The solids are incinerated to a minute quantity of sterile ash. The incinerator normally operates at 500,000 BTU's per hour burner output with less than 0.5 pounds of fuel per minute and a sludge rate of 0.33 gallons per minute.

The clarified supernatant is drawn off the top of the separator for disinfection by chlorination.

All tanks are vented through the positive flow electro-coagulation cell vent duct which is separated from the incinerator exhaust stack. Each tank in the plant has a drain and is tied to a drain system. The specifications for a SWTS system are presented in Table 7.

Centrifugation-Ozonation-Incineration unit (Grumman Ozotherm)

Grumman Ozotherm (48) is designed to treat all of the sanitary wastes from a ship. Sewage flows through a screening device. The screened sewage then passes to a centrifuge to separate the solids from the liquid. A sludge pump periodically transfers the accumulated solids to an incinerator for complete combustion. Clear liquid from the centrifuge is ozonized prior to discharge. Figure 24 is a system schematic diagram.

A curved stainless steel screen is completely enclosed in a fiberglass housing with sewage flowing through by gravity. A compact clarifier, providing over 1400 gallons capacity, consists of a stainless steel inner bowl, a reinforced fiberglass housing, cast aluminum alloy base and lid, self lubricating bearing, and an electric motor. An automatic scraper recover accumulated sludge periodically for transferring to the incinerator.

Ozone is generated from a compact multitube ozonator employing the corona-discharge principle. An integral compressor and automatic cycling drying tower provides dry air for conversion. A counterflow stainless steel column is designed to provide optimal contact time and maximum mixing of the ozone/air mixture with the clarified liquid from the centrifuge. Complete combustion of the waste is achieved in a pyrolytic chamber. The specifications of an Ozotherm are presented in Table 7.

Maceration-Chlorination Filtration Unit (Wilson Water Purification Corp. Model MACL)

Three models have been produced to treat the sewage at capacity of 1500 and 5000 gallons per day. System (49) is designed to allow the sewage and chlorine contact for several hours. Sewage is macerated and chlorinated prior to discharge. A system schematic is shown in Figure 25.

All units except the hypochlorinator and control panel are housed in a cylindrical holding tank. The tank is baffled and divided into four sections. Section A contains a screen type rag catcher basket and a macerator. Chlorine is applied at this section. A tablet dissolving type hypochlorinator mounted on the top of the tank serves as a chlorine feeder. Section B is used as a long holding chamber for chlorine contact and recirculation. Larger particles settle and are removed toward the macerator by hydraulic turbulence. Finer particles are carried with the liquid over a weir into section C where a folder screen serves to return large solids for remaceration. An eductor pump is equipped in section D to pump out the treated effluent. The specifications are presented in Table 7.

Interceptor-Incinerator (Babcock & Wilcox System)

The Babcock & Wilcox system (50) has been developed to treat all of the sanitary wastes from a ship by utilizing the interception, disinfection, and incineration concepts. There are three models of the system which are referred to as Mark I - the non-recycling arrangements; Mark II - the recycling arrangement; and Mark III - the consolidating arrangement. The discharge from galley, heads, showers, sinks, and laundry are collected, aerated, and disinfected in a holding tank. Upon activation by an integral control system, the waste matter is macerated and pumped to a waste gun that injects the fluid into the ship's main propulsion boiler furnace. In the boiler furnace, the fluid is reduced to essentially steam and inert ash. Figure 26 shows the typical flow sheet of the system.

A surge tank with a capacity of 150 gallons is utilized to accept the flow and equalize the operating cycles of the system to ensure a steady state process. Sewage is then ground and transferred by a pump grinder.

A 100-gallon disinfectant tank with mild mechanical mixing is used to maintain a uniform distribution of solids in suspension. Sodium hypochlorite is added at a pre-determined rate to maintain a disinfectant concentration of up to 200 ppm as Cl_2. The disinfectant tank is sized to provide approximately ½ hour retention time before overflowing to the main holding tank. The main holding tank is continuously aerated to assist in maintaining a fresh effluen. Approximately 1½ days accumulation can be accomodated in the main holding tank to handle periods when the main boiler loading is too low for incineration. From the holding tank, the effluent is then subjected to another pump grinder and is either recirculated to the main tank or fed directly to the boiler. The atomizing suspension purpose is accomplished by applying 2-fluid spray nozzles.

Combustion of the waste water in the boiler furnace would add 5 % by weight of non-pathogenic ash to the oil ash, thus this technique has no need of extra space for an incinerator. The alternative arrangement of connecting the holding tank effluent to a shore discharge allows a dual function of retaining the sewage or destroy the sewage on board, and both can meet the future no-discharge requirement. The specifications are presented in Table 7.

Adsorption-Incineratipn UNit (Fram Sanitary Treatment System)

The Fram Marine Waste Treatment System (51) is of the aerobic biological type, using activated carbon as an adsorbent to remove soluble organics. The system consists of four major modules: solids handling, liquid waste removal, regeneration, and disinfection.

The solids handling module serves to remove the insoluble solids. The raw wastes are received on the top of a self-cleaning screen, which vibrates in two planes, causing the solids to move horizontally across the screen to the periphery. As the solids build up, they are discharged directly to an incinerator. The incinerator is maintained at a temperature of 1600 ^{o}F where complete combustion occurs. After the solids have been removed, the wastewater is heated by means of a water jacket around the incinerator to accelerate biological action.

Removal of soluble organic matter is accomplished by passage of the waste water downflow through packed beds of activated carbon. The final treatment involves the addition of chlorine before overboard discharge.

On a programmed time sequence, the activated carbon beds are regenerated. This is accomplished by passing the liquid from the regeneration vessel to the carbon beds in an upflow mode, expanding the carbon vessels, then back to the regeneration vessel. This serves to elute the adsorbed organic matter to the regeneration vessel. Air is added to the regeneration vessel through air diffusers to produce fine dispersed air bubbles, which in turn transfer oxygen to the liquid. The high dissolved oxygen content of the regeneration liquid supplies the oxygen necessary to ensure an active biological population.

The regeneration of the carbon beds is a continuous process with one-third of the system being regenerated, while two-thirds of the total system is available for treatment.

A system schematic is shown in Figure 27. The specifications of a FRam system are presented in Table 7.

Incineration Toilet (Incinolet)

Incinolet (52) uses heat alone to reduce human waste, both solids and urine, to inorganic,odorless and bacterial-free ash. All models are equipped with a blower which is locked electrically with the heater. The blower is always on when the heater is on. Both heater and blower are actuated simultaneously. After the heater cuts off, the blower stays on until the incinerator chamber cools to room tempertaure. Moisture and other vapors driven off during incineration are vented to the atmosphere by the blower and vent line. The blower is integral with theunit. Residual ash is accumulated in an ashpan located at the bottom of the unit which is emptied once or twice monthly. To use the incinerating toilet, a wax-vapor liner is utilized to carry the water from the bowl to the incinerator chamber. The liner prevents the waste from contacting thebowl surfaces. The user drops the liner into thebowl prior to use. After use, the incinolet is flushed by stepping on the foot pedal. The incineration cycle is actuated by the flushing action.

A catalytic odor control device is associated with the heater. The catalyst, when heated, causes the odor molecules to degenerate into other type molecules. Figure 28 shows a general arrangement of the system. The specifications are presented in Table 7.

Incineration Toilet (Destroilet)

The Destroilet (53) is an incinerator enclosed in a functional housing. It disposes of wastes by way of agas flame the operates automatically only after the lid has been closed. It has the ability to let toilet facilities for up to approximately 60 times per day.

Operation of the Destroilet is automatic. Rising the seat winds the timer, lifts the heat shield and actuates a forced draft system which draws air through the lid, allows the timer to begin its cycle, lower the heat shield, and starts the burner.

The timer controls the cycle, which consists of two phases; a burn cycle followed by a cool down cycle.

The specifications of a Destroilet are presented in Table 7.

Controlled Volume Flush Holding Tank (Colt's Envirovac)

The Envirovac system (54) involves the use of air instead of water for the transport of sewage. The raw sewage piping is held under a constant 7 psia vacuum produced by a vacuum pump. Toilets of special design are connected to the piping by means of discharge valves controlled by the flushing mechanism in each toilet. When the discharge valve opens, atmospheric air enters the system transporting sewage through the pipes, in the form of a liquid plug, to a connecting tank. The entire flushing cycle takes 7 seconds, including water spraying for cleaning and filling the bowl. Less than 3 pints of water is required for each flush.

The system results in a 90 % reduction in the volume of flushing water used. Piping need be only 2 inches in diameter and since no gravity transport is required, pipes can be placed without slopes and worked around obstacles.

The specifications of an Envirovac system are presented in Table 7.

Controlled Volume Flush Evaporation Unit (GATX ETS-125)

With specially designed commodes, a small flush volume of water (1.25 gallon per man per day) carries human wastes via a macerating pump to a concentration and holding tank. The system (55) consists of four major subsystems; (1) controlled-volume flush commode, (2) macerator-transfer pump, (3) evaporator, and (4) control for operation and service.

The macerator transfer pump, with 1½ HP and a 50 feet head at 30 gpm, receives, grinds, and moves wastes. Each time a commode is flushed, the macerator pump transfers liquid and solid wastes into the evaporator. Valving at each pump outlet prevents the back-flow of liquids, solids, and odors into the commode and pump section.

A dye disinfectant solution is added to the flush water when the commode is flushed. The addition of this solution is automatic and proportional to the flush volume. The disinfectant inhibits bacteria growth within the slurry during transfer of wastes from the commode to the evaporator. Once within the evaporator the wastes are boiled at 212 ^{o}F; this converts the water in the waste products to steam which is vented to the atmosphere. The dye and disinfectant solution are also used as a wetting agent to aid in maintaining a clean commode. The reservoir for thesolution, the injection hardware, and the controlled volume flush hardware combine to complete the commode assembly.

The evaporator is a 125-gallon stainless steel tank with teflon inner lining and fiberglass insulation. Wastes pumped into the evaporator accumulate to a specific volume which in turn actuates a level sensor thereby energizing the evaporator heating system. Heating and boiling at ambient pressure continue until the waste solids content in the evaporator reaches the desired level. At this time, sensors and electrical controls signal the end of the service cycle and prevent further heating.

A drain valve is provided at the bottom of the evaporator for gravity draining of the evaporator sludge. This sludge is pumpable and can be removed to an incinerator or approved disposal facilities. The control panel provides sufficient warning before evaporator service is imminent. After the evaporator has been emptied and rinsed, all controls are reset and the waste collection cycle is started again.

A system schematic is shown in Figure 29, and the specifications of a GATX-ETS 125 system are given in Table 7.

Systems not Commercially Available yet (Late 1973)

A system being developed by General American Transportation Corporation (56) will be capable of handling sanitary and galley waste from 6 - 20 men at an average flow of 700 gpd. The system is based on physical treatment using a hydrophylic filter for primary treatment, hydromation filter, carbon adsorption for secondary treatment and disinfection for bacterial control. The process provides 90 % reduction of BOD and SS and produces an effluent with coliform count of less than 240/100 ml. Immediate start up and shut down at anytime and for any length of time is possible without diminishing the system effectiveness.

Incoming sewage is first treated by the hydrophylic filter which utilizes a moving screen and the hydrophylic capacity of a moving sponge to achieve solids-liquid separation. The hydromation filter and granular activated carbon columns further reduce BOD and SS to less than 100 ppm. Chlorine is finally applied to reduce coliform to below 240/100 ml. The system under development will weigh about 3500 lbs and will have dimensions of 6 ft by 2 ft by 8 ft. On board disposal of separated solids is required. Power consumption is estimated at about 500 watts. The system my be put into the market in late 1973.

Figure 30 shows the system schematic.

Wet-Oxidation Unit (Zimpro Marine Wastewater Treatment System)

A system being developed by Zimpro Inc. (57) will be capable of handling sanitary and galley wastes for 500 men at an average flow of 10000 gallons per day. The system is based on the process which has been described before. The process provides 90 % reduction of BOD and leaves 30 ppm of SS and essentially no coliform bacteria in the effluent.

Screening-Incineration Unit (RSC Xpurgator)

The Unit (58) is developed and designed mainly to treat the human body waste. It involves the steps of moving the sewage to a filtration area. Solids are removed by deposit on a moving porous medium through which the aqeous medium passes to a filtered liquid accumulator. The porous medium carries the deposited solids through a thermal chamber where the deposited materials are destroyed. Figure 31 shows the system schematic.

Filtration-Adsorption Unit (Ametex System)

The Ametex system macerates the incoming sewage and mixes it with a disinfectant and a flocculant. The chemically treated liquor is then subjected to the process of in-depth filtration and carbon adsorption. Effluent from the filtration/adsorption unit is discharged overboard, whereas the used filter/adsorption media and the entrapped sludge are discharged into a disposal cannister. Figure 32 shows the system schematic.

Adsorption-Catalytic Oxidation Unit (AWT System)

The AwT system accomplished the filtration and incineration in one stage (59). Sewage enters the incinerator, coarse solids are caught on a bar gate and the finer solids are entrapped in the filtering medium. The solids are then destroyed by propane fired incineration.

After passing through the filter, the filtrate is polished off in a carbon adsorption bed and then chlorinated before discharge.

The combustion products are passed through a catalytic oxidizer which effectively destroys the odor. System schematic is shown in Figure 33.

Carbon Adsorption Unit (Gulf & Western System)

The Gulf & Western system utilizes powder activated carbon on a once-through, throw away basis (59). The waste discharged from the bowls is pushed into a carbon injector-mixer. The pressure differential between the two rubber joker valves causes the carbon-water slurry to be drawn from the bottle container and injected into the chamber. Baffles within the chamber induce a turbulent flow and mix the waste with the carbon slurry. Outflow from the mixer-injector is piped to a filtration-collector unit which then discharges the resultant purified effluent. The solids which are collected are bagged for disposal. Figure 34 shows the system schematic.

Pyrolysis-Aeration Unit (Reid Pyrolysis-Aeration Unit)

Four steps are involved in Reid's system (60): biooxidation, separation, pyrolysis, and disinfection. Raw sewage is introduced through a colloidal mill into an aeration chamber where the liquid is aerated with air. A centrifuge is applied to separate the suspension from the liquor. Concentrated sludge is then subjected to a complete distruction by heat in a pyrolysis chamber using atomizing suspension technique, whereas the clear liquid is disinfected by recovering the waste heat from the flue gases prior to discharge or to reuse. The temperature in the pyrolysis chamber is maintained at 1500 ^{o}F to eliminate the odor and ensure an efficient pyrolysis process. Figure 35 shows the system schematic.

Interception-Incineration Unit (Fairbank-Morse Toilet Waste Treatment System)

The Fairbanks-Morse system (59) is a modification of Colt's interception-incineration unit. Waste discharge from the bowls is intercepted by a set of revolving disks to remove the large solids. Liquid which flows through is mixed with coagulant prior to filtration. A paper consisting of a continuously moving paper bed and shredder unit is utilized as filtration device. Effluent from the paper filter is further subjected to carbon adsorption and disinfection prior to reuse.

Ultimate solids disposal is accomplished through incineration. Spent paper and carbon are also disposed of in the incineration unit. Figure 36 shows the system schematic.

Centrifugation-Adsorption Unit (Delaware River & Bay Authority Waste Treatment System)

The Delaware River & Bay Authority system (59) involves fivesteps: preliminary screening, centrifugation, solids storage, carbon adsorption, disinfection with overboard discharge and recirculation. Waste discharge from the toilet bowls is first treated with a vibrating screen for large solids removal. Effluent from this screen is further subjected to a centrifuge for the finer solids separation. Carbon columns are utilized for the purpose of dissolved solids removal. Accumulated solids are stored in a storage tank for periodic disposal at shoreside facilities. Figure 37 shows a system schematic.

Table 7. Alternative's Specifications for Shipboard

Sewage Management Systems

Alternative	(A)*	(B)*	(C)*	WEIGHT Dry	WEIGHT Wet	(D)*	(E)*	EFFLUENT QUALITY BOD	EFFLUENT QUALITY SS	EFFLUENT QUALITY COLI	(F)*	(G)*	(H)*	(I)*
I. Holding Tank Systems														
Wilcox-Crittenden Holding Tank	22	24" 20" 13"	0.9	22	155	5.5 38.75	20 min.	0	0	0	15 min.	-	-	Deodorant
Monogram Jet-O-Matic	16	19" 24½" 25¼"	0.83	28	172	3.5 21.5	20 min.	0	0	0	20 min.	N/A	-	Deodorant
Newmatic	14	18" 19¼" 25"	0.62	45	189	5.62 23.62	20 min.	0	0	0	20 min.	N/A	-	Deodorant
THetford Corp. Sea Farer	4	16" 18" 14¼"	0.58	10	46	2.5 10.0	30 min.	0	0	0	-	-	-	Deodorant
Electra Magic	4	20¼" 16" 20¼"	1.08	20	56	5 14	30 min.	0	0	0	-	-	-	Deodorant
Aqua Magic	4	17¼" 16" 19¼"	0.77	15	51	4 13	30 min.	0	0	0	-	-	-	Deodorant
Porta Potti	4	18½" 13½" 18½"	0.66	10	46	2.5 12	30 min.	0	0	0	-	-	-	Deodorant

Table 7 (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	EFFLUENT QUALITY SS	EFFLUENT QUALITY COLI	(F)	(G)	(H)	(I)
Mansfield Vacuum Flush system	12	12" 9" 15" + 12 Gal.	0.63	115	218	28.75 54.50	20 min.	0	0	0	20 min.	N/A	-	-
	15	12" 9" 15" + 15 Gal.	0.73	120	250	30.0 62.5	20 min.	0	0	0	25 min.	N/A	_	-
	20	12" 9" 15" + 20 Gal.	0.45	185	355	23.12 44.37	20 min.	0	0	0	25 min.	N/A	-	-
	30	12" 9" 15" + 30 Gal.	0.27	191	451	10.61 25.05	20 min.	0	0	0	30 min.	N/A	-	-
Aquatic Designs Holding Tank	30	32" 22" 12"	0.81	28	300	4.66 50.0	10 min.	0	0	0	10 min.	-	-	-
Jonny Trap Holding Tank (Jr-12)	12	16¼" dia. 21" H.	0.62	21	131	5.25 32.75	10 min.	0	0	0	10 min.	-	-	-

Table 7 (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI.	(F)	(G)	(H)	(I)
Jonny Trap Jt 20	20	19¼" dia. 24" H.	1.01	25	209	6.25 52.25	10 min.	0	0	0	10 min.	-	-	-
Jt 30	30	22" dia. 28"H.	0.75	35	311	4.37 38.87	10 min.	0	0	0	15 min.	-	-	-
Jt 40	40	24¼" dia 30"H.	1.02	45	431	5.62 53.87	10 min.	0	0	0	15 min.	-	-	-
Potpourri Model #707	6	18" 19" 14½"	0.71	12	60	3 15	30 min.	0	0	0	5 min.	-	-	9% Forma- dehyde and 15 % Zinc Sulfate.
Model #737	12	17" 18" 19"	0.56	14	110	2.33 18.33	30 min.	0	0	0	5 min.	-	-	
Kracor Holding Tank R61	6	13" 13" 11"	0.25	14	N/A	3.62	10 min.	0	0	0	10 min.	-	-	-
R89	9	19" 13" 11"	0.25	17	N/A	2.75	10 min.	0	0	0	10 min.	-	-	-

Table 7. (cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Kracor Holding Tank														
R120	12 12"	20" 14" 12"	.23	18	N/A	2.25	10 min.	0	0	0	15 min.	-	-	-
R160	16	37" 13" 11"	.30	25	N/A	2.5	10 min.	0	0	0	15 min.	-	-	-
R252	25	28" 19" 13"	.25	31	N/A	2.06	10 min.	0	0	0	15 min.	-	-	-
Jensen Model 770	8	20" 22" 17"	1.08	23	95	5.75 23.75	10 min.	0	0	0	10 min.	-	-	-
II. Biological Treatment Systems														
Bio-Pure BP6D	600	8' 4'6" 4'	14.4	1300	6050	130 605	2 hrs.	20	20	300	0	3KWH/day	-	Hypochlorite Tablets
BP12D	1200	7'2" dia 7' H.	14.0	1800	10000	90 500	2 hrs.	20	20	300	0	3.5KWH/day	-	
BP20D	2000	7'8" dia	10.91	2000	13750	62.85 392.85	2 hrs.	20	20	300	0	4KWH/day	-	

Table 7. (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Bio-Pure														
BP30D	3000	9'4" 8' 8'	11.9	3600	20750	72.0 415	2 hr.	20	20	300	0	4.5 KWH/day	-	
BP50D	5000	13"10" 8' 8'	11.0	4700	31900	58.75 398.75	2 hr.	20	20	300	0	5.1 KWH/day	-	
BP75D	7500	8' 18'4" 8'	9.76	6400	42900	53.33 357.50	2 hr.	20	20	300	0	5.5 KWH/day	-	
BP100D	10000	8' 8' 18'4"	6.50	8000	60900	44.44 338.33	2 hr.	20	20	300	0	6.0 KWH/day	-	
Red Fox														
RF-3000-M	300	16' 9'2" 8'8"	17.04	8974	44770	119.65 596.93	1 hr.	30	100	15	0	10KW	-	Sodium Hypochlorite
Demco														
Wt-2200	2200	10' 6' 5'	8.57	5270	19530	150.57 555.14	1.5 hr.	25	50	100	-	3 KWH/day	-	Bacteria-Enzyme, Chlorite Tablet.
WT-325	325	7.5' 3' 3'	13.5	2100	4720	420.0 944.0	1.5 hr.	25	50	100	-	1.5 KWH/day	-	

Table 7. (cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Demco														
Wt-625	625	7' 5' 3'	10.50	3150	7330	315 733	1.5 hr.	25	50	100	-	1.8 KWH/day	-	Bacteria-Enzyme, Chlorite Tablet.
WT-1000	1000	7.5' 5' 4'	10.00	3859	10000	256.5 666.6	1.5 hr.	25	50	100	-	2.1 KWH/day		
WT-1250	1250	7' 5' 5'	8.75	4250	13360	212.5 618.0	1.5 hr.	25	50	100	-	2.4 KWH/day		
Wt-1565	1565	9' 5' 5'	9.0	4570	14800	182.8 592.0	1.5 hr.	25	50	100	-	2.7 KWH/day		
WT-1875	1875	10' 5' 5'	8.3	4880	16500	162.6 551.7	1.5 hr.	25	50	100	-	3.0 KWH/day		
WT-2500	2500	11' 6' 5'	8.2	5650	21310	141.3 532.7	1.5 hr.	25	50	100	-	3.5 KWH/day		
WT-2815	2815	10' 6' 6'	8.0	5870	23650	130.4 525.5	1.5 hr.	25	50	100	-	4.0 KWH/day		
WT-3125	3125	11' 6' 6'	7.92	6200	25420	124.0 508.4	1.5 hr.	25	50	100	-	4.4 KWH/day		

Table 7. (cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Demco Wt-3750	3759	12' 7' 6'	8.4	7800	32200	130.0 536.6	1.5 hr.	25	50	100	-	4.9 KWH/day	Bacteria- Enzyme Chlorite Tablet.	
WT-5000	5000	7' 7' 13'	7.96	8700	40360	108.7 504.5	1.5 hr.	25	50	100	-	5.3 KWH/day		
WT-6000	6000	7' 7.5' 15'	8.28	8850	48600	93.15 511.6	1.5 hr.	25	50	100	-	5.8 KWH/day		
WT-7000	7000	7' 17' 7.5'	8.11	9800	55050	89.09 500.45	1.5 hr.	25	50	100	-	6.3 KWH/day		
WT-8000	8000	19' 7.5' 7'	7.67	10650	61630	81.92 500.45	1.5 hr.	25	50	100	-	6.8 KWH/day		
WT-9000	9000	18' 8' 7.5'	7.44	11100	67890	76.50 468.20	1.5 hr.	25	50	100	-	7.2 KWH/day		
WT-10000	10000	20' 8' 7.5'	7.50	11550	76500	72.18 478.12	1.5 hr.	25	50	100	-	7.4 KWH/day		
WT-12500	12500	26' 7.5' 8'	7.80	15015	78609	75.07 493.45	1.5 hr.	25	50	100	-	8.0 KWH/day		

Table 7. (cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	EFFLUENT QUALITY SS	EFFLUENT QUALITY COLI	(F)	(G)	(H)	(I)
Weldco	2000	10' 8' 7'	16.96	7000	17000	212.12 515.15	2 hr.	N/A	N/A	N/A	-	7HP	-	HTH 75 %
IWC M5000	5000	7' 8.4' 8'	4.64	5000	10000	50 100	7 hr.	50	50	50	-	4.5 HP	-	5% Sodium Hypochlorite
Bio-Flo	N/A	18" 20½" 25½"	1.36	80	N/A	20	N/A	20	N/A	0	-	-	-	Tri-chloro-s-triajinetrilone.
Microphore M-10	80	12" 14" 48"	1.16	48	100	12 25	1 hr.	N/A	N/A	0	-	-	-	Chlorine
M-12	80	30" 12" 24"	1.66	40	140	13.3 46.66	1 hr.	620	125	0	-	-	-	
III. Physical-Chemical Treatment Systems														
Jered VACU-BURN System	N/A	80" 60" 66"	1.22	6600	8000	4.4 53.33	3.0 hr.	0	0	0	0	6KW	180gpd marine Diesel	-
Chrysler Aqua-Sans A	600	84" 30" 54"	3.93	850	1500	42.5 75.0	2 hr.	0	0	0	0	0.9 KW	Diesel or LPG	

Table 7. (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Chrysler Aqua-Sans A-1	1500	99" 40" 54"	2.47	950	1900	19.0 38.0	2 hr.	0	0	0	1.0 KW	Diesel LPG	or	2-10 ppm Isotri-chloro-cyanmic acid
B	5000	140" 53" 66"	1.77	1750	3750	10.93 24.43	2 hr.	0	0	0	0	1.2 KW		
C	10000	177" 65" 80"	1.66	2300	6100	7.18 19.06	2 hr.	0	0	0	0	1.4 KW		
Colt M175CM	N/A	84" 54" 66"	0.86	4400	7900	22 39.50	2 hr.	150	100	0	0	103 KWH/day	#2 8gpd	
M5000CM	N/A	8'10" 12'6" 7"8"	1.71	13000	18000	26 36	2 hr.	100	150	0	0	400 KWH/day	#2 20gpd	
Thiokol MPB-10	30	3' 3' 4'	3.6	200	320	20 32	0.7 hr.	0	0	0	-	4KW	3% Sodium Hypo-chlorite.	
Thiokol Navy system	6000	8' 6' 14'	3.36	13700	16300	68.50 81.50	-	50	40	0	-	33KW	120 gpd.	

Table 7 (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
St. Louis Ship FAST-15	450	115" 75" 90"	29.94	5000	13000	333.3 860.6	0.7 hr.	0	0	o	-	4KW	-	3% Sodium Hypochlorite
Lundy UF-5	5000	750ft^3	15	4200	14800	84.00 296	4 hr.	50	0	0	1.5 hr.	18KW	-	$FeCl_2$ & Poly-electrolyte 0.7lbs/day
Ocean System	3	30" 16" 21"	0.97	125	150	20.83 25.0	0.5 hr.	0	0	0	-		0.2 gpd oil.	
Westinghouse system	8	22.75" 20" 18"	1.18	175	256	43.75 64	1 hr.	0	0	0	-	0.9 KWH/day	0.2 gpd oil	$Ca(OCl)_2$ tablet
Koehler-Dayton MSTS	N/A	10' 8' 6'	0.96	4800	6500	9.6 13.0	2 hr.	0	0	0	0	1KW	DF_2 Diesel fuel 3-5 gph.	6% Para-formal-dehyde.
Seapax Model 20	N/A	5'6" 2'6" 5'6"	3.78	1700	3000	85 150	2½hr	0	0	0	-	3HP	-	0.1 % caustic Alka-linity, Tri-chloro iso-cyanurate.

Table 7 (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Seapax Model 50	N/A	6'6" 3' 6'	2.34	2000	4200	40 84	2½ hr.	0	0	0	-	5Hp	0.1 % Caustic Alkalinity, Trichloro isocyanurate.	
Model100	N/A	7'6" 3'6" 6'6"	1.70	2500	6200	25 62	2½ hr.	0	0	0	-	6HP		
FMC MSD-1 Model 50-2000 4000		8' 4' 6'8"	2.16	2500	3200	25 32	3 hr.	50	10	0	-	-	Celite 17.3 # per 1000 gal., Activated carbon 5.7#/1000 gal. Cl_2 0.4 #/ 1000gal. Alums 4.8#/1000Gal. Acdifying Agent 3.5#/1000gal.	
Model 50-3000 8000		8' 4' 6'8"	1.08	2600	3300	13 16.5	3 hr.	50	10	0	-	-		
Model 50-4000 8000		106" 48" 81"	1.19	3100	4000	15.5 20	3 hr.	50	10	0	-	-		
Model 50-8000 50000		18' 8' 8'8"	2.52	8000	16000	16 32	3 hr.	50	10	0	-	-		

Table 7. (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	SS	COLI	(F)	(G)	(H)	(I)
Hyde Park Treatment System	6000	N/A	-	N/A	N/A	-	1 Hr.	100	40	0	-	10Hp	-	Chlorine
Geaeral Electric SWTS	4000	6' 7' 12'	-	7800	12000	-	1 hr.	75	50	100	-	-	-	-
Grumman Ozotherm	1500	6' 4' 4'	1.92	1500	2100	30 42	2 hr.	50	50	3	0	5.7KW	20gpd	Ozone
	5000	7½' 6½' 6'	2.34	2750	4250	22 34	2 hr.	50	50	3	0	7.8KW	60gpd	
	25000	14' 8½' 6½'	1.28	7500	13260	125 22.10	2 hr.	50	50	3	0	27.5 KW	300gpd	
	50000	18½' 10½' 6½'	1.01	14700	23700	11.76 19.12	2 hr.	50	50	3	0	45.7 KW	600gpd	
Fram Sp-10	1000	N/A	-	-	-	-	½ hr.	50	50	0	-	-		Sodium Hypochlorite.
Babcock & Wilcox Mkja	4800	12'3" 7'9" 12'3"	9.56	11100	49900	92.5 415.8	20 min.	0	0	0		diesel		Sodium Hypochlorite

Table 7. (Cont'd)

Alternative	(A)	(B)	(C)	WEIGHT Dry	WEIGHT Wet	(D)	(E)	EFFLUENT QUALITY BOD	EFFLUENT QUALITY SS	EFFLUENT QUALITY COLI	(F)	(G)	(H)	(I)
Wilson's MACL	1500	165 gal	0.63	N/A	2000	57.14	30 min.	N/A	N/A	0	-	N/A	-	Chlorine
	2500	300 gal	0.66	N/A	3200	53.32	30 min	N/A	N/A	0	-	N/A	-	Chlorine
	5000	525 gal	0.56	N/A	5280	42.24	30 min.	N/A	N/A	0	-	N/A	-	Chlorine
Fram SP-20	2000	N/A	-	N/A	-	-	-	50	50	0	-	-		Sodium hypochlorite
SP-50	5000	-	-	-	-	-	-	50	50	0	-	-		
SP-75	7500	-	-	-	-	-	-	50	50	0	-	-		
Incinolet	8	$20\frac{1}{4}$" 15" $23\frac{1}{4}$"	0.68	N/A	-	-	20 min	0	0	0	-	3650W	-	-
Destroilet	8	17" 17" 17"	0.35	55	70	6.87 8.75	30 min	0	0	0	-	36W	13000 BTU/Hr.	
Envirovac	N/A	-	-	-	-	-	1 hr.	0	0	0	2 Hr.			
GATX ETS-125	30	50 ft^3	2	500	1050	20 45	1 hr.	0	0	0	1 Hr.	5KW		Formaldehyde.

* (A): Capacity, Gallons/day

(B): Dimensions

(C): Space Requirement, Ft^3/man.

(D): Weight Requirement, #/man.

(E): Supervision hours required per week, Hours.

(F): Pump out time required, Hours.

(G): Power requirement.

(H): Fuel Consumption.

(I): Chemicals and consumable goods required.

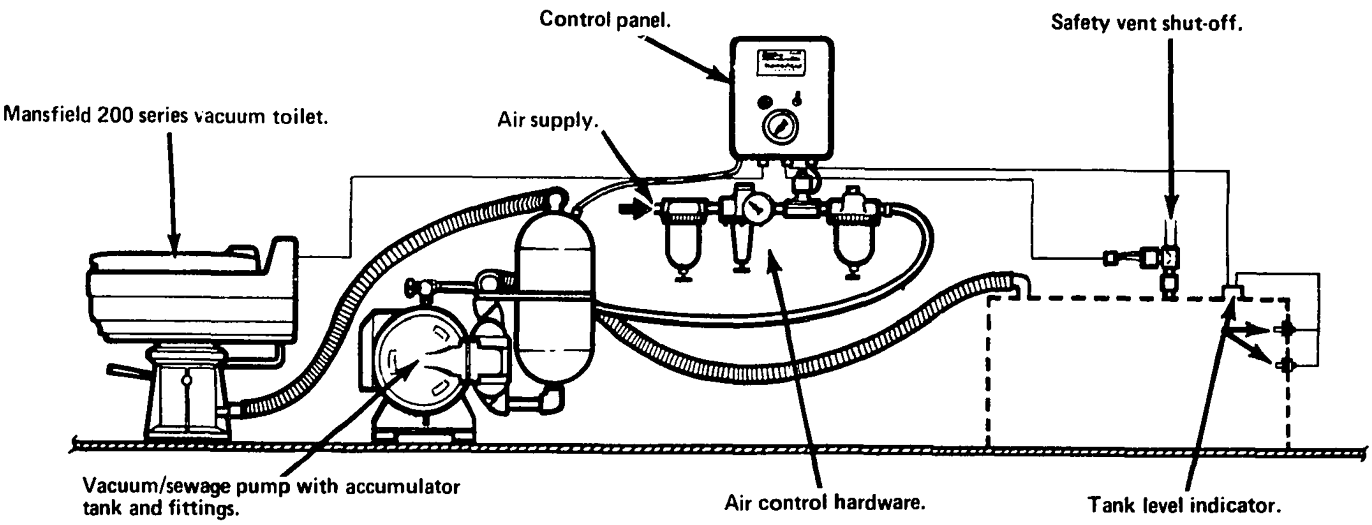

Figure 4. Mansfield VACU-FLUSH.

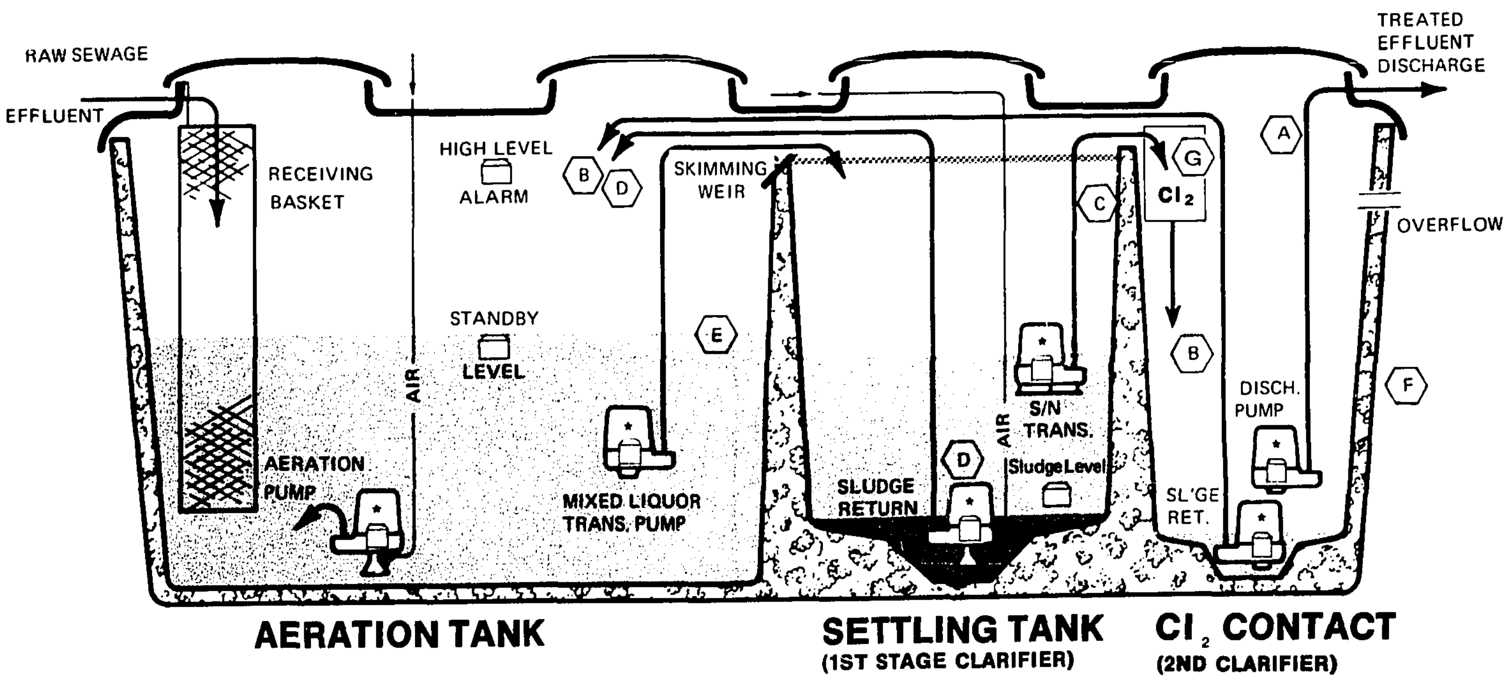

Figure 5. Bio-Pure system.

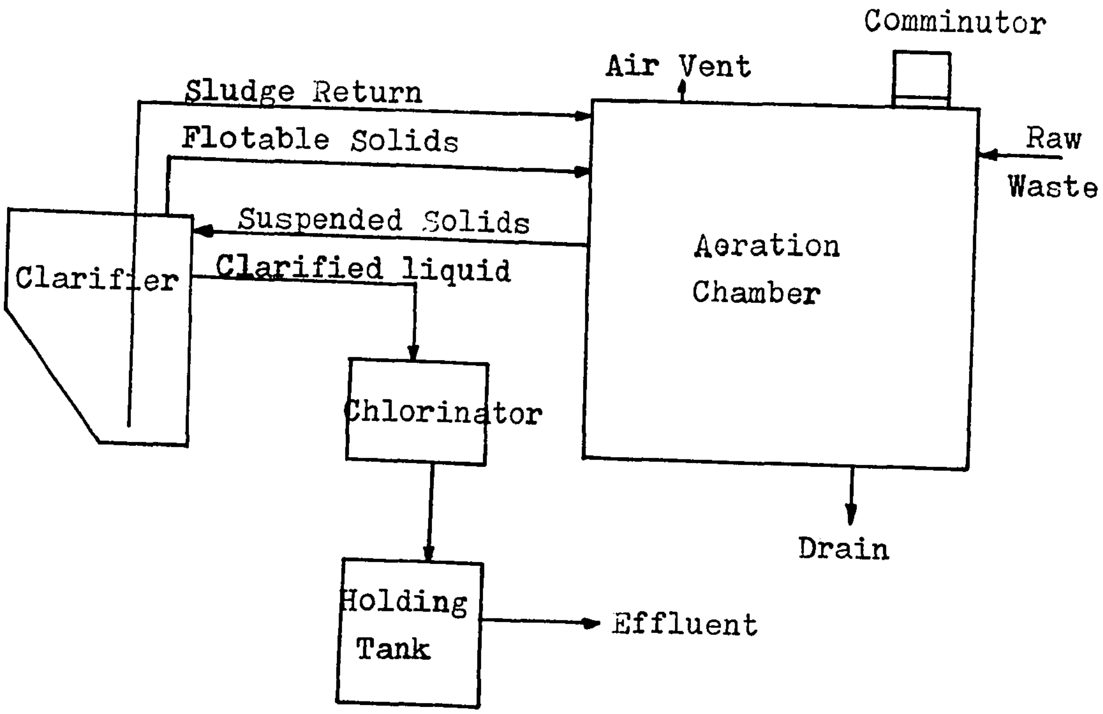

Figure 6. Red Fox Marine Sewage Unit.

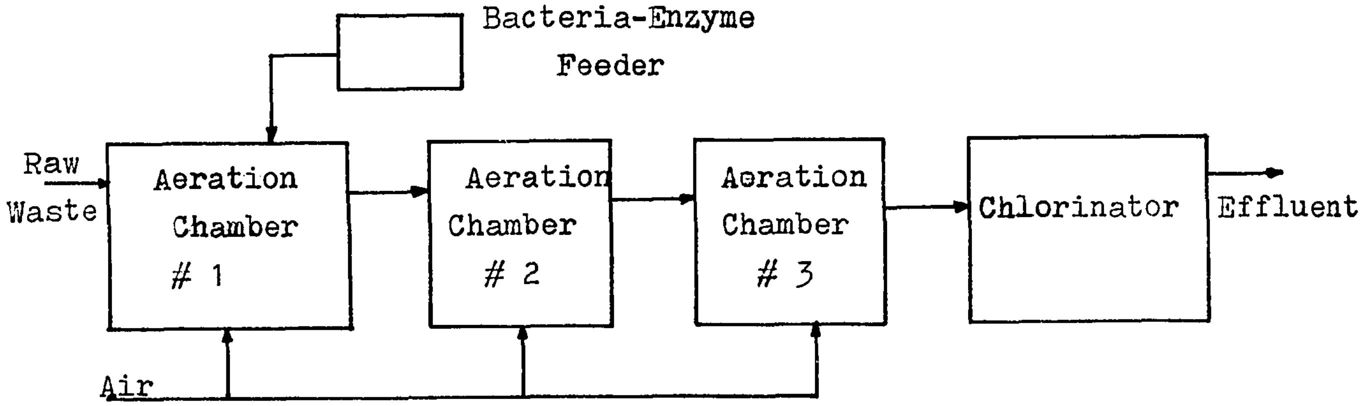

Figure 7. Demco Waste Treatment System.

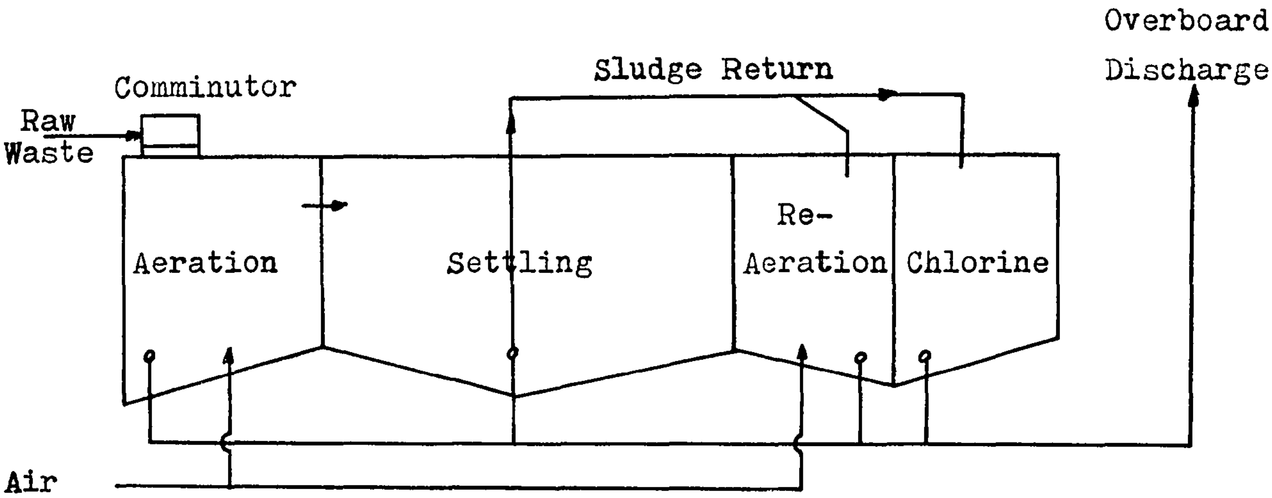

Figure 8. Weldco Aerobic Treatment System.

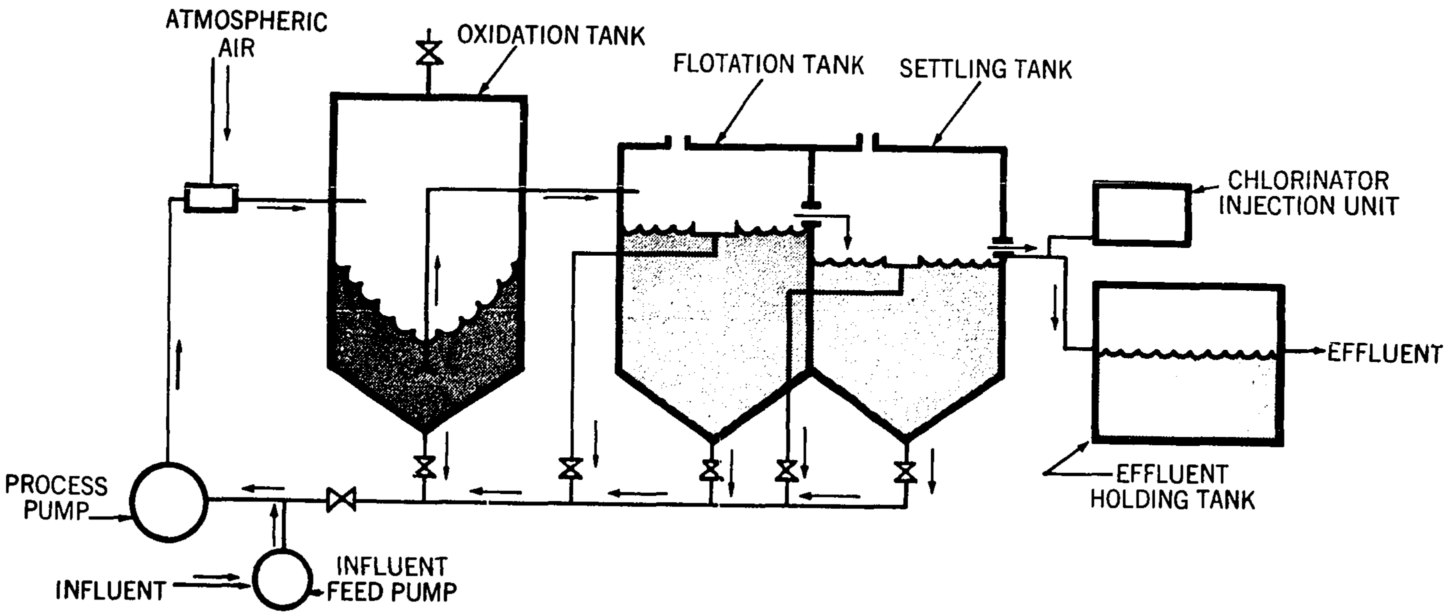

Figure 9. IWC System.

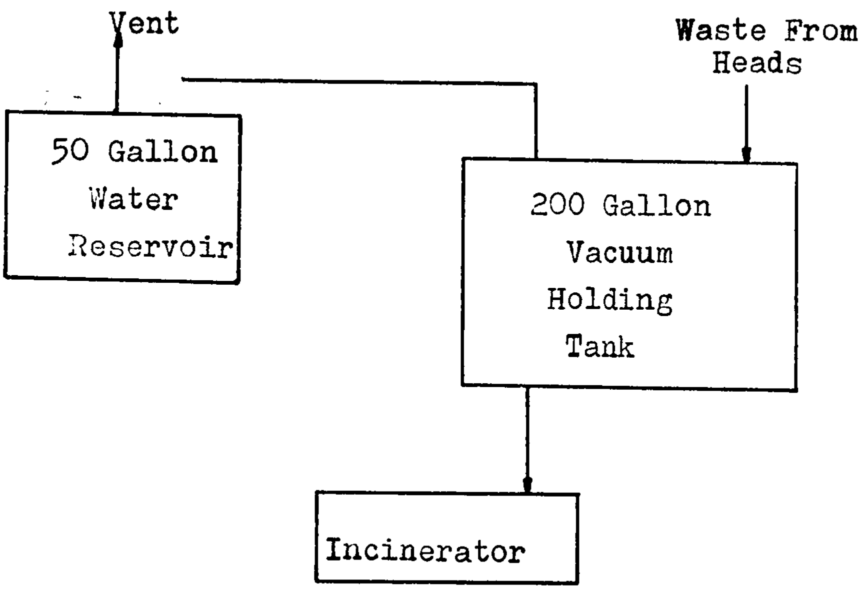

Figure 10. Jered VACU-BURN System.

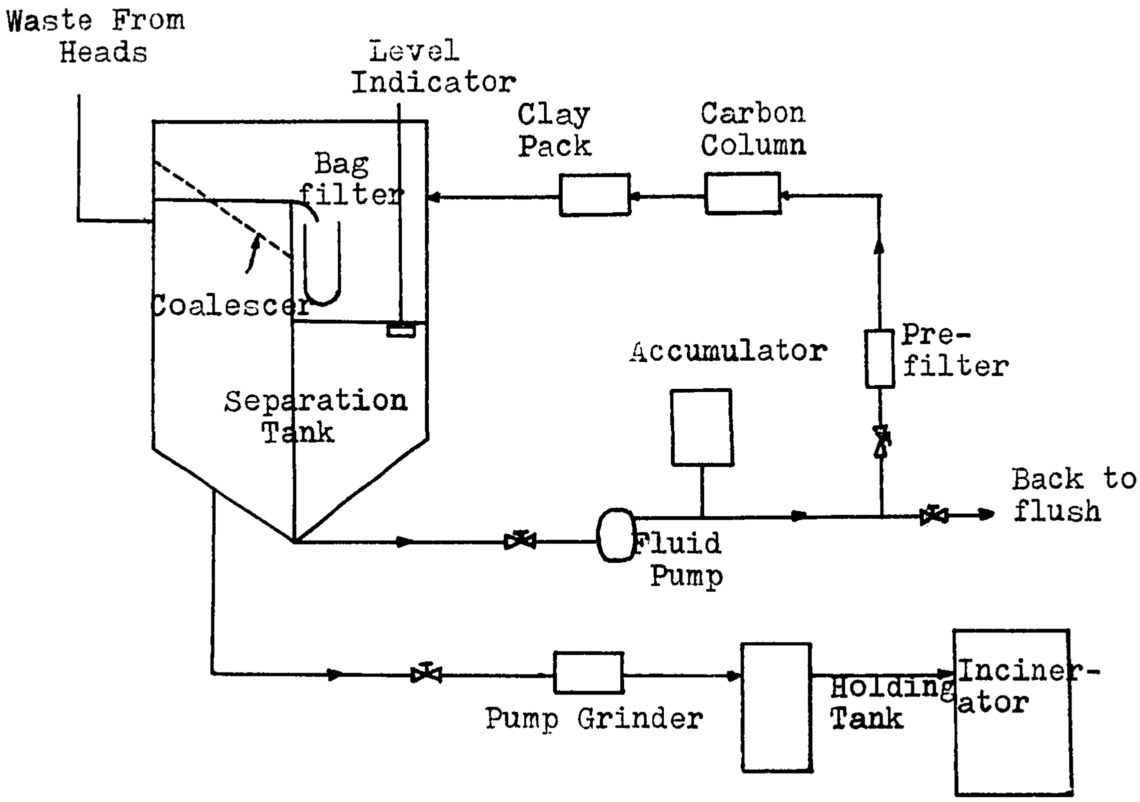

Figure 11. Chrysler Aqua-Sans Sewage Treatment System.

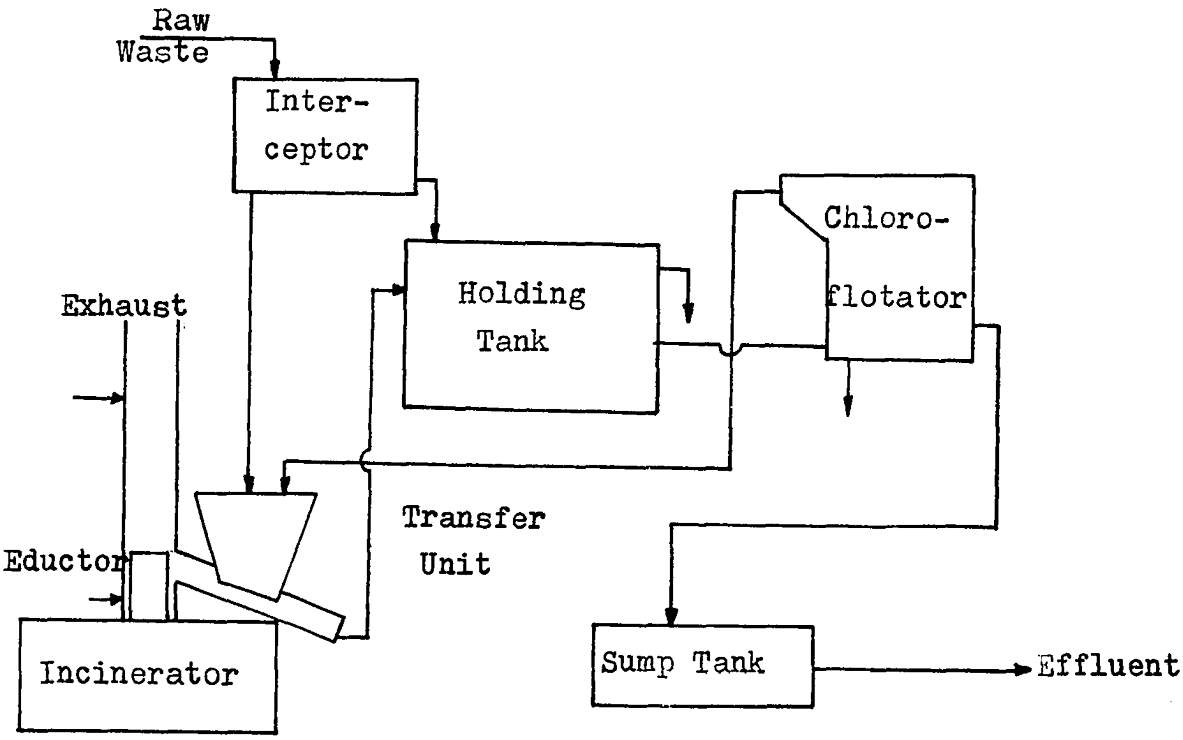

Figure 12. Colt's Electrolysis-Incineration Unit.

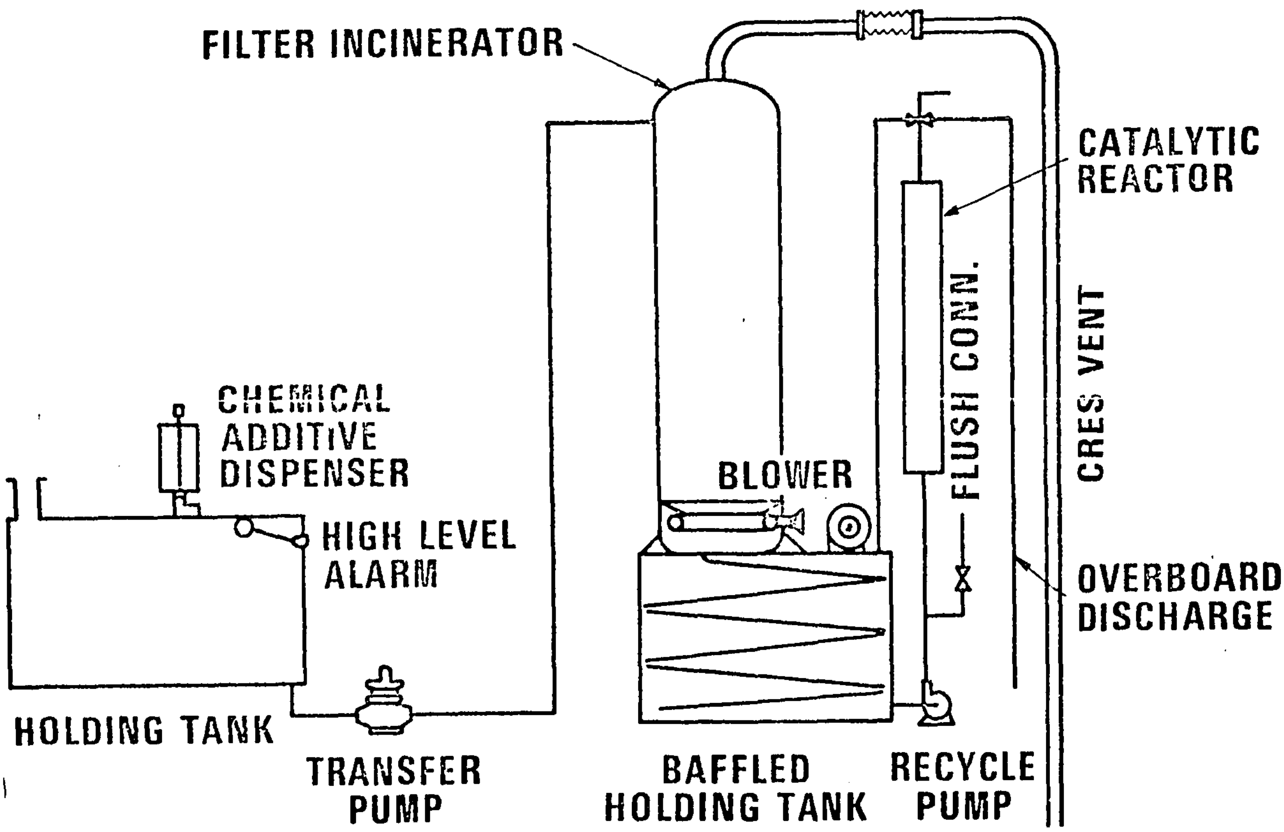

Figure 13. Thiokol MPB-10.

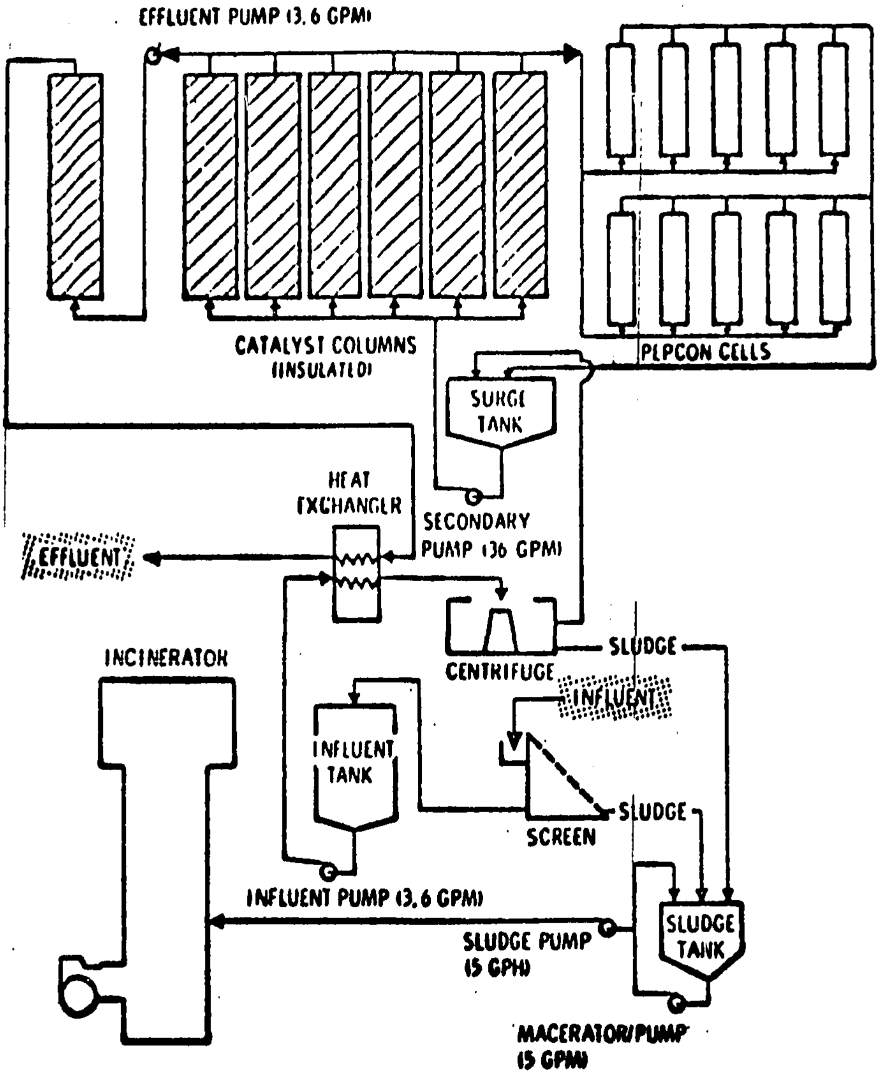

Figure 14. Thiokol Non-Biological Waste Treatment System.

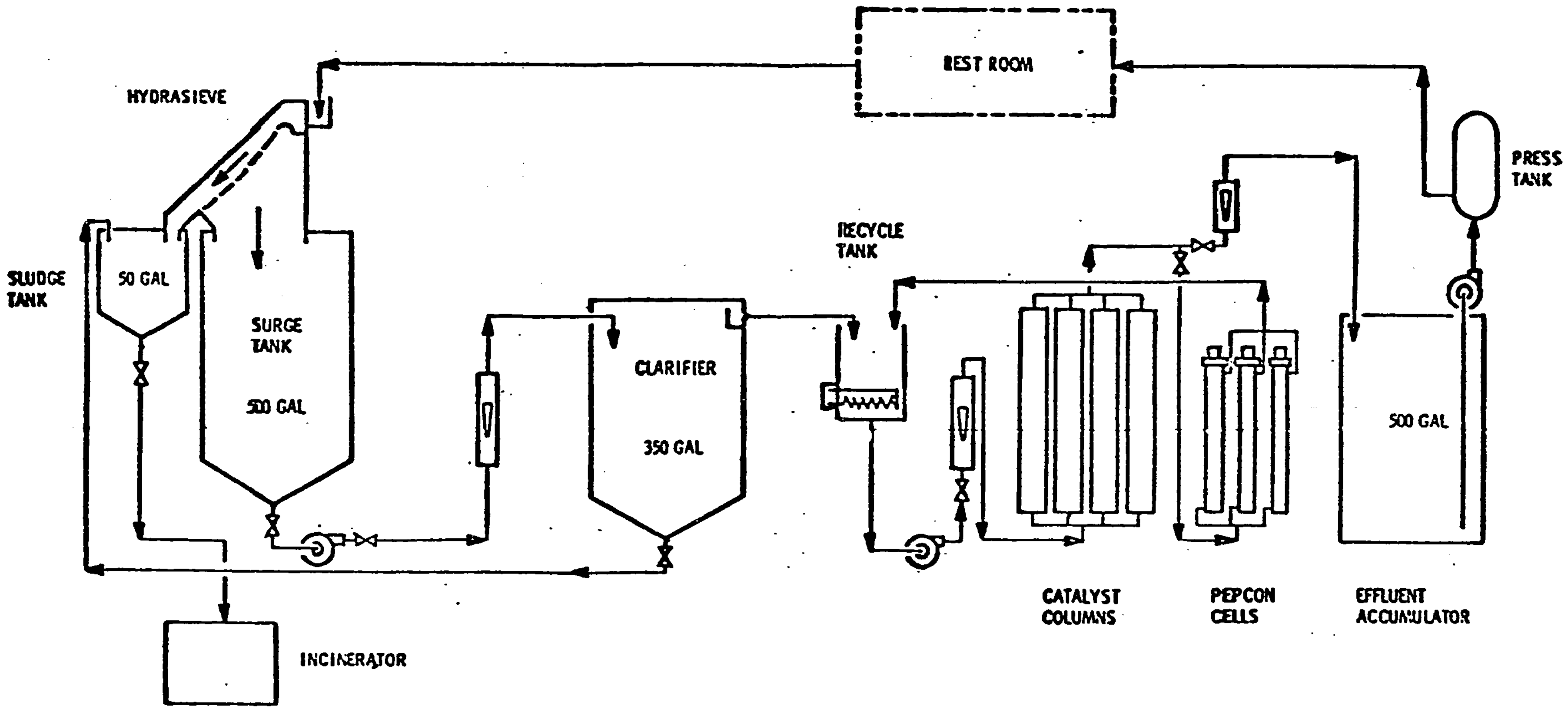

Figure 15. Thiokol Modified Non-Discharge Schematic.

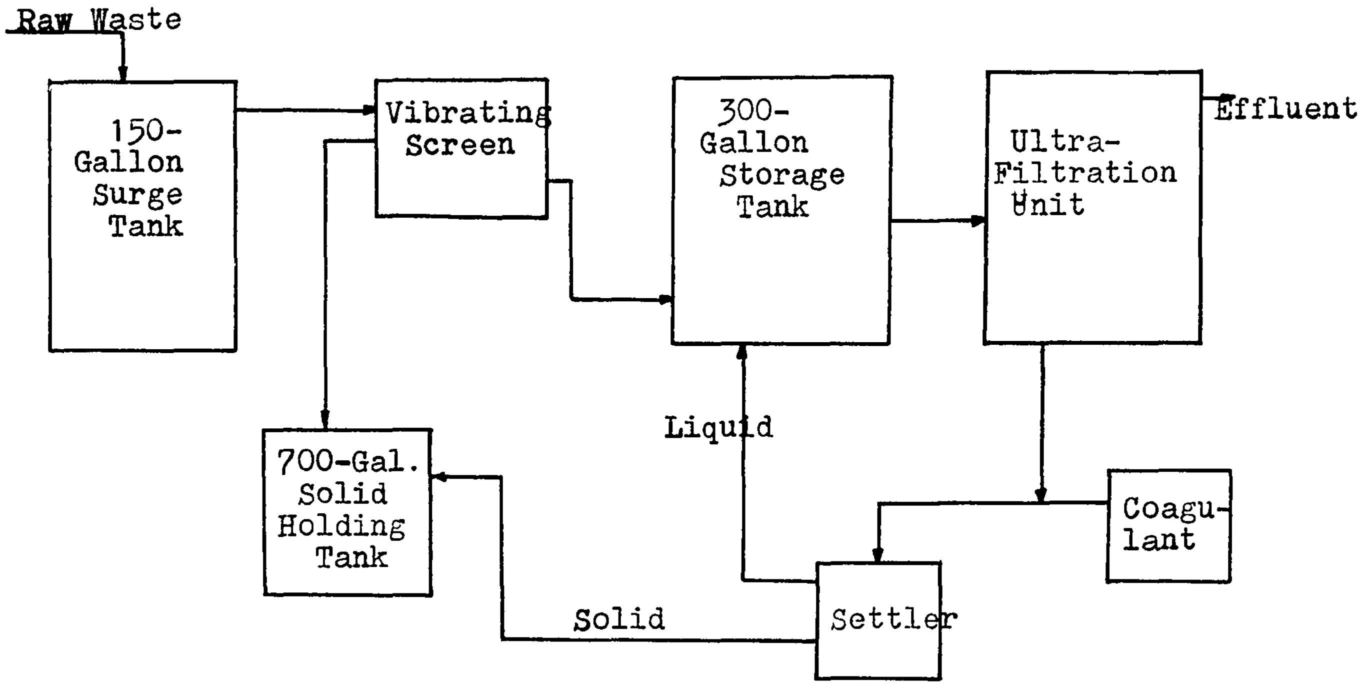

Figure 16. Lundy UF-5.

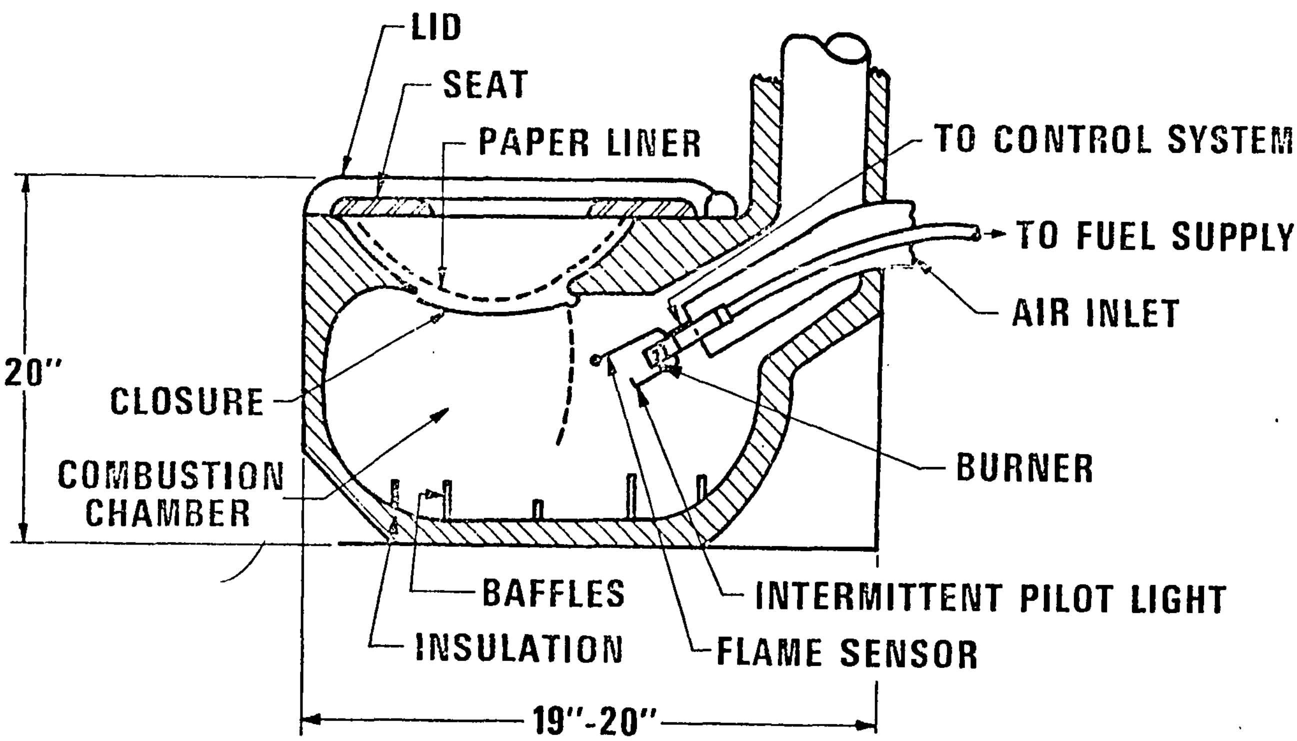

Figure 17. Ocean System Inc. Incineration Toilet.

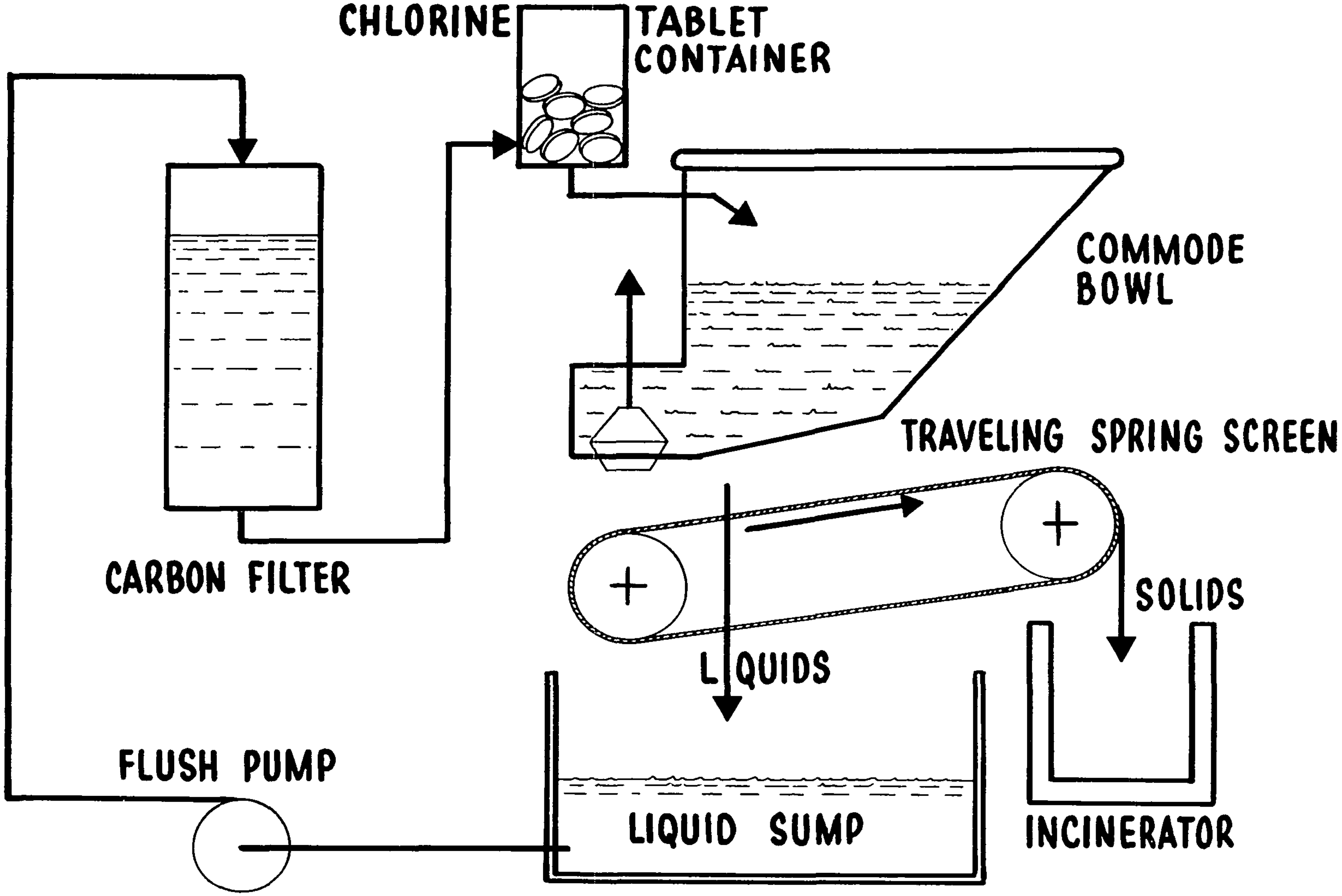

Figure 18. Westinghouse System.

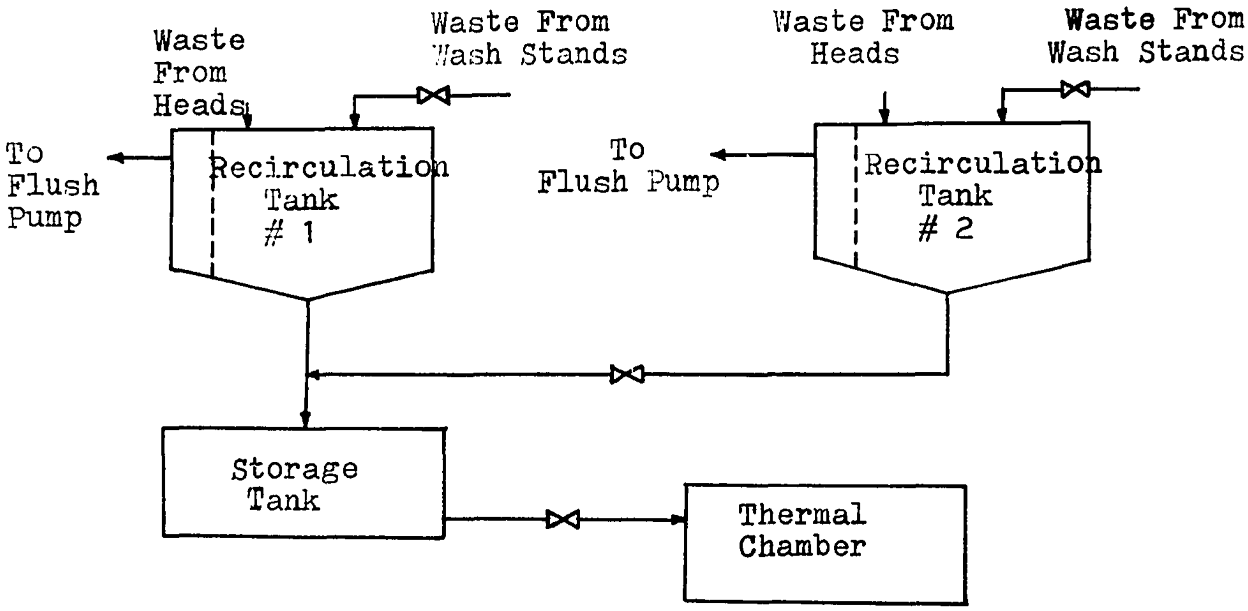

Figure 19. Koehler-Dayton MSTS.

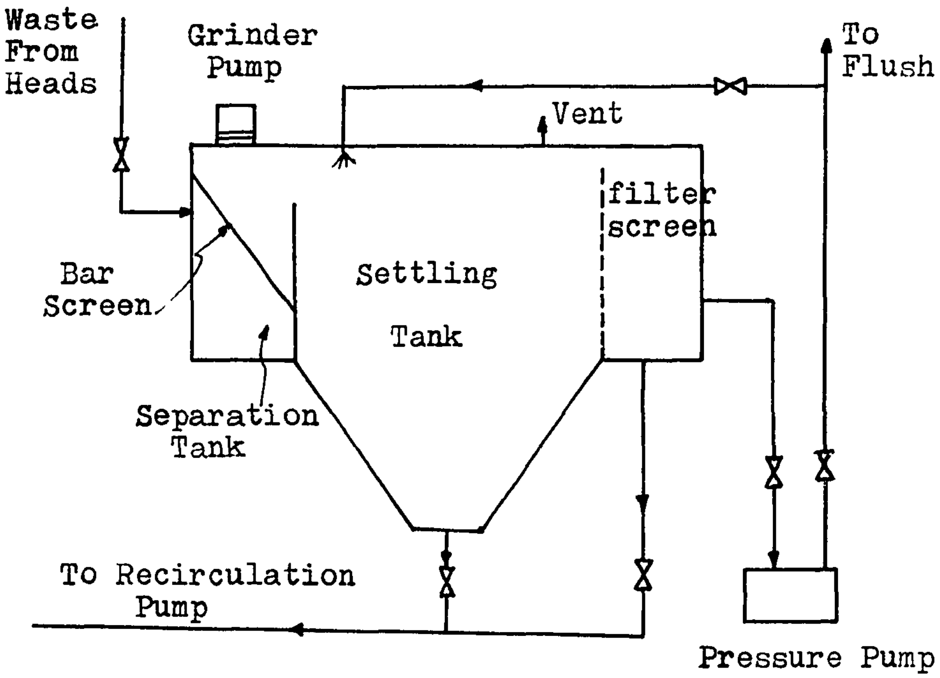

Figure 20. Seapax System.

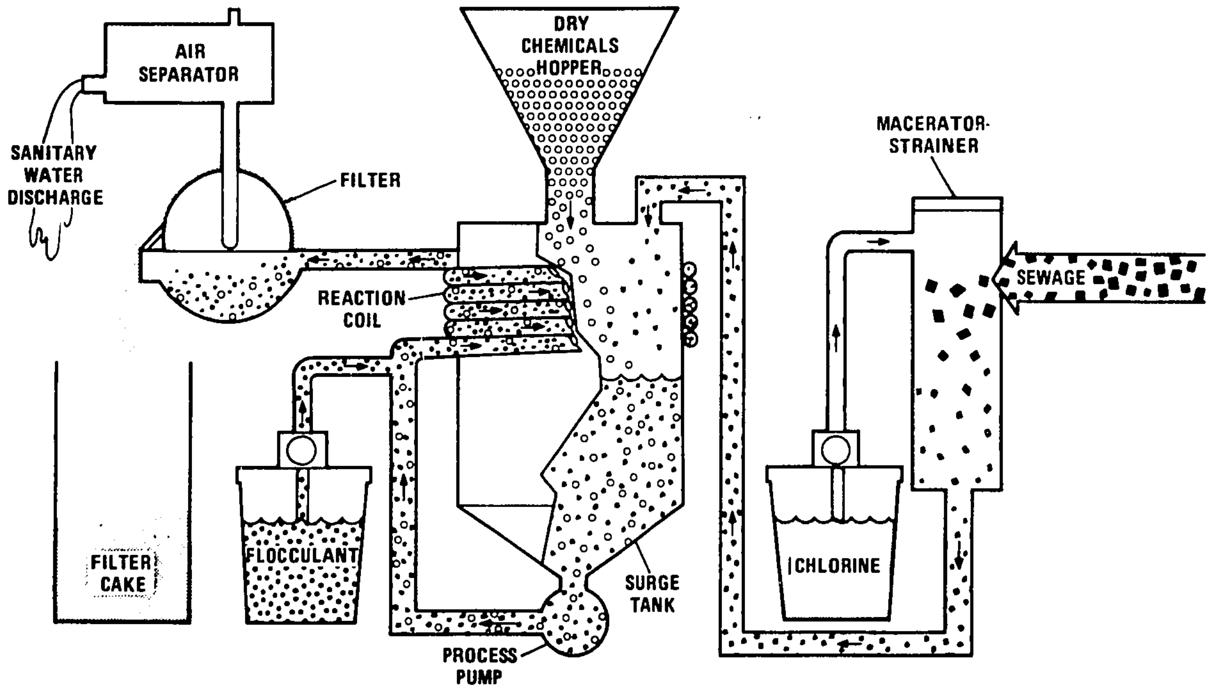

Figure 21. FMC Marine Sanitation Device.

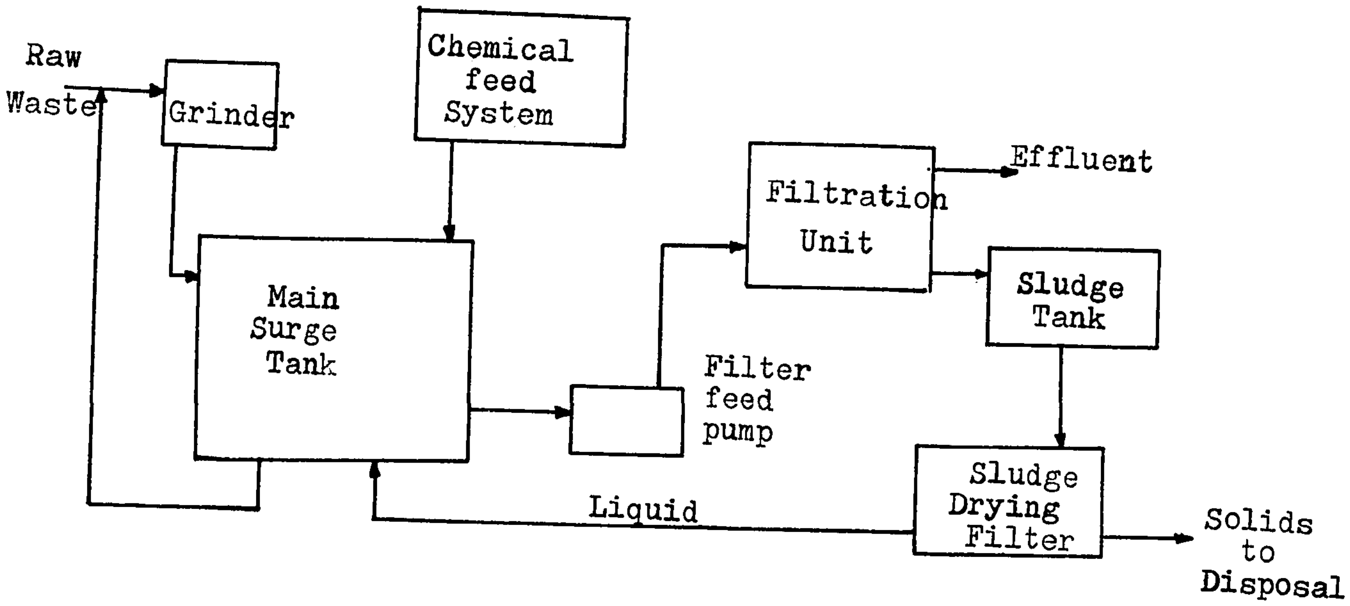

Figure 22. Hyde Waste Treatment System.

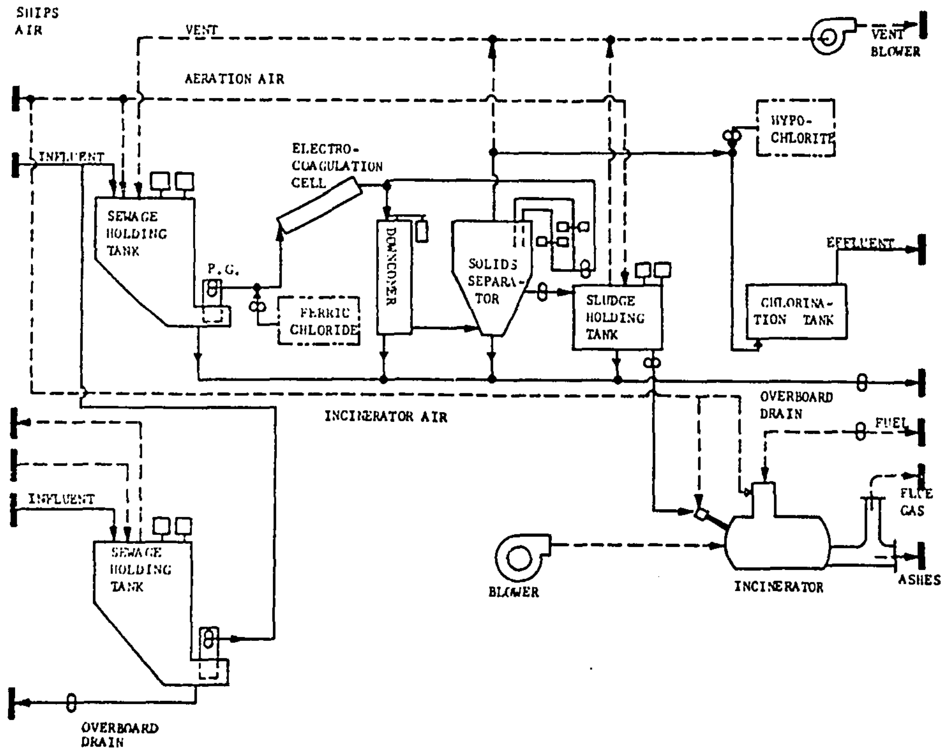

Figure 23 General Electric SWTS

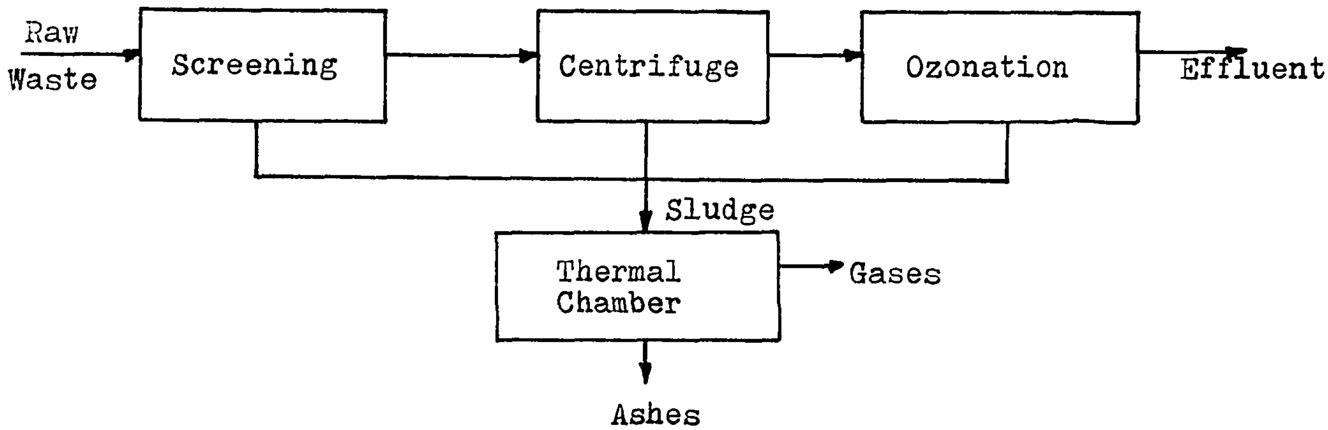

Figure 24. Grumman Ozotherm.

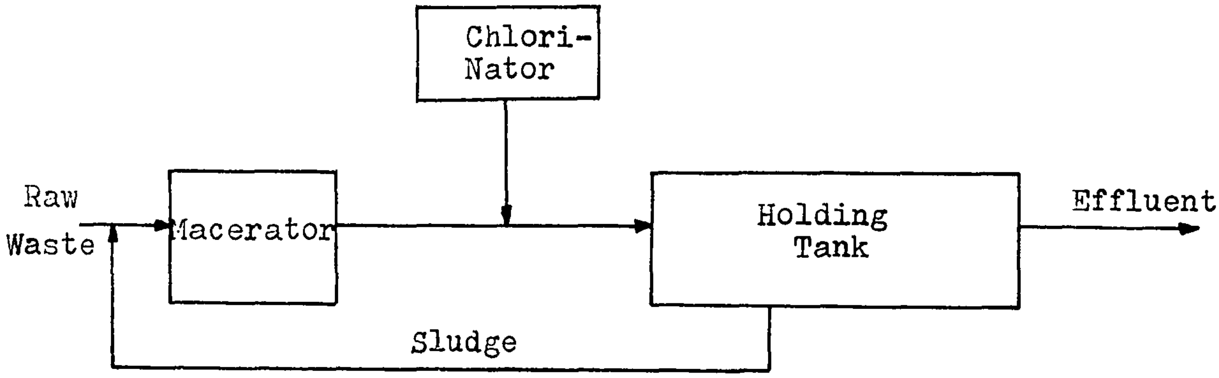

Figure 25. Wilson Water Purification Corp. Model MACL.

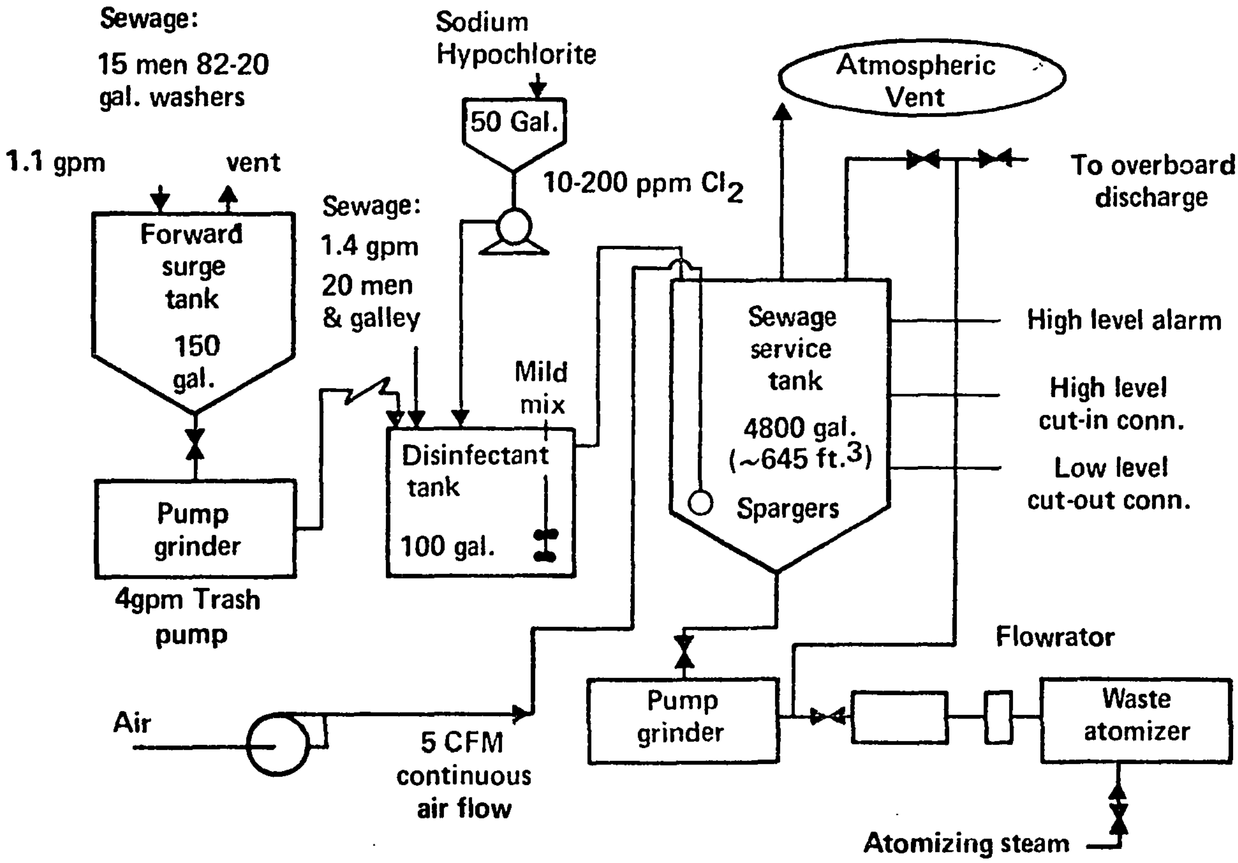

Figure 26. Babcock and Wilcox System.

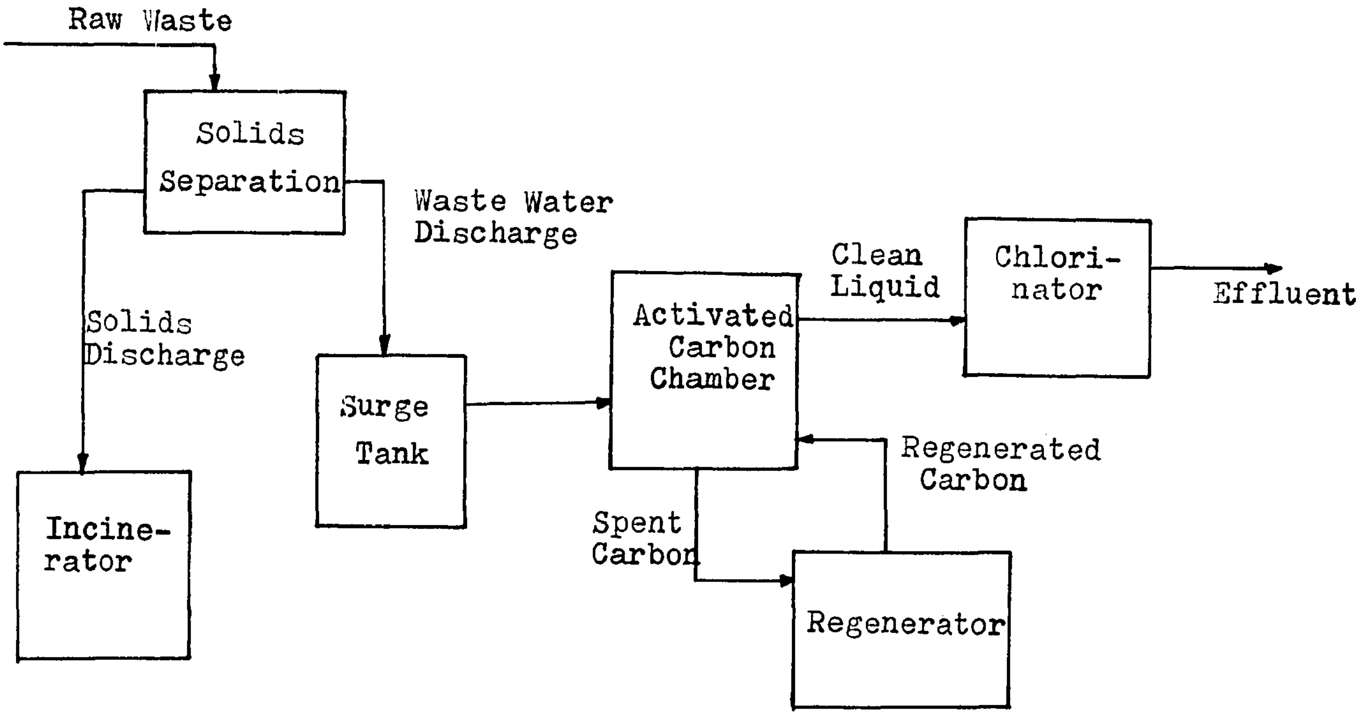

Figure 27. Fram Sanitary Waste Treatment System.

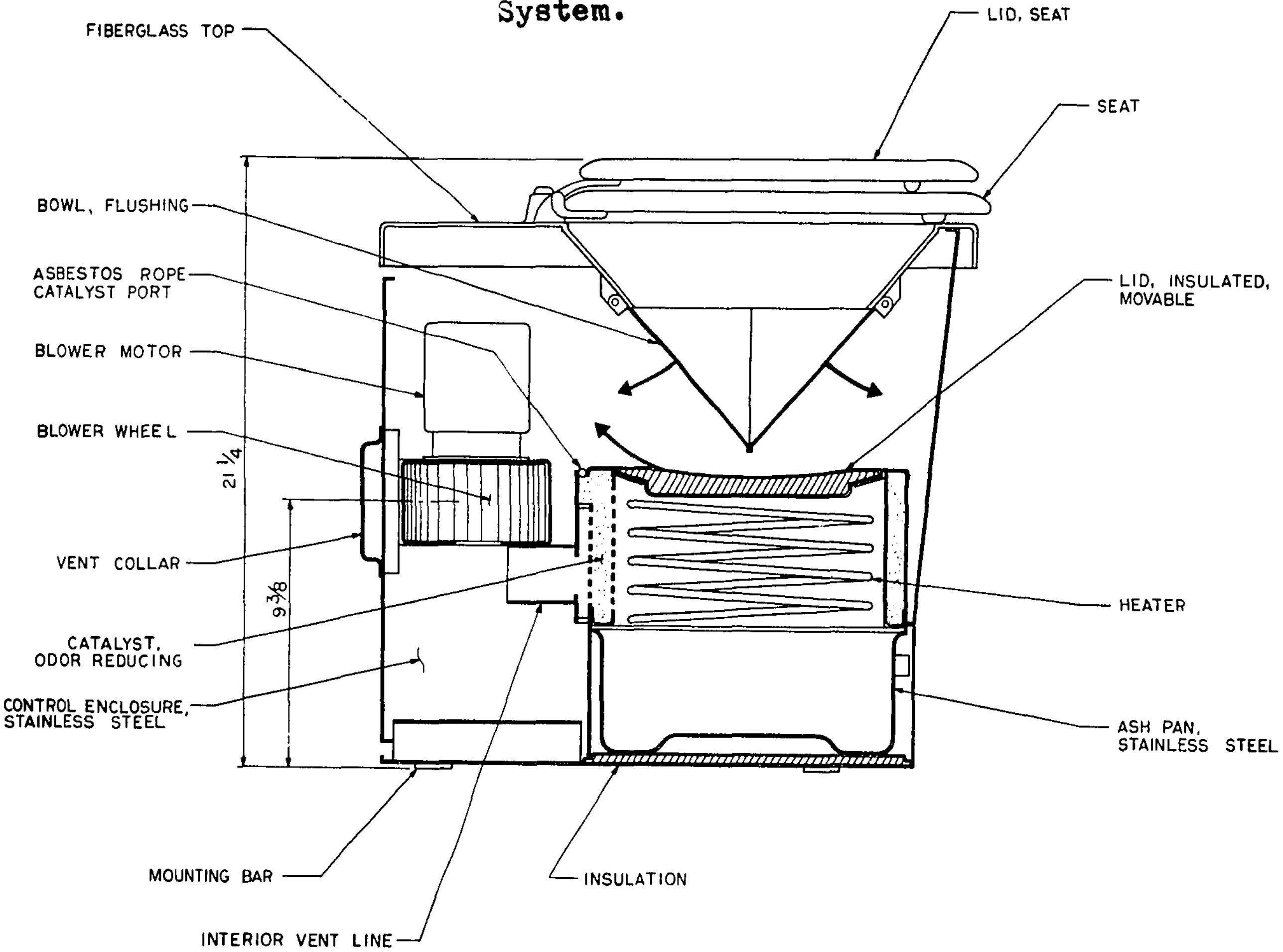

Figure 28. Incinolet.

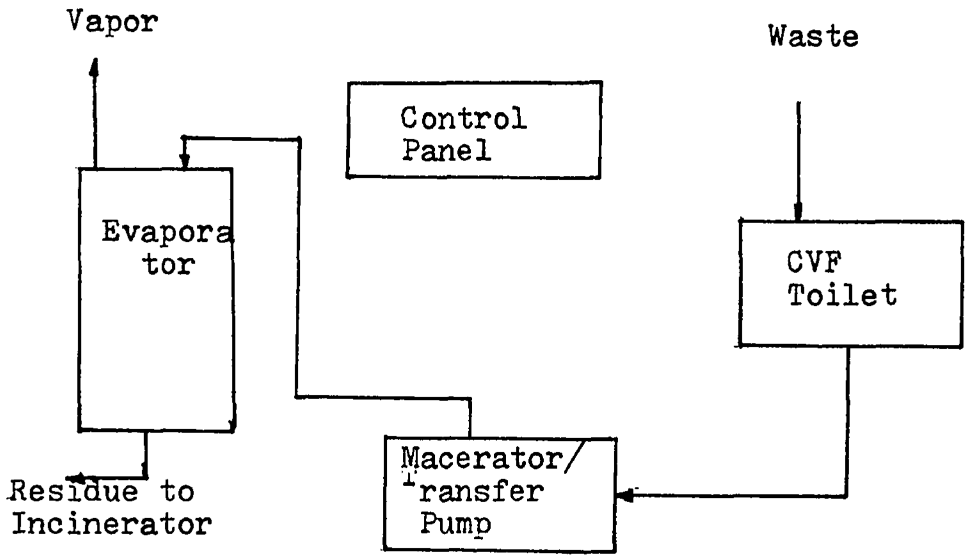

Figure 29. GATX Controlled Volume Flush Evaporation Unit

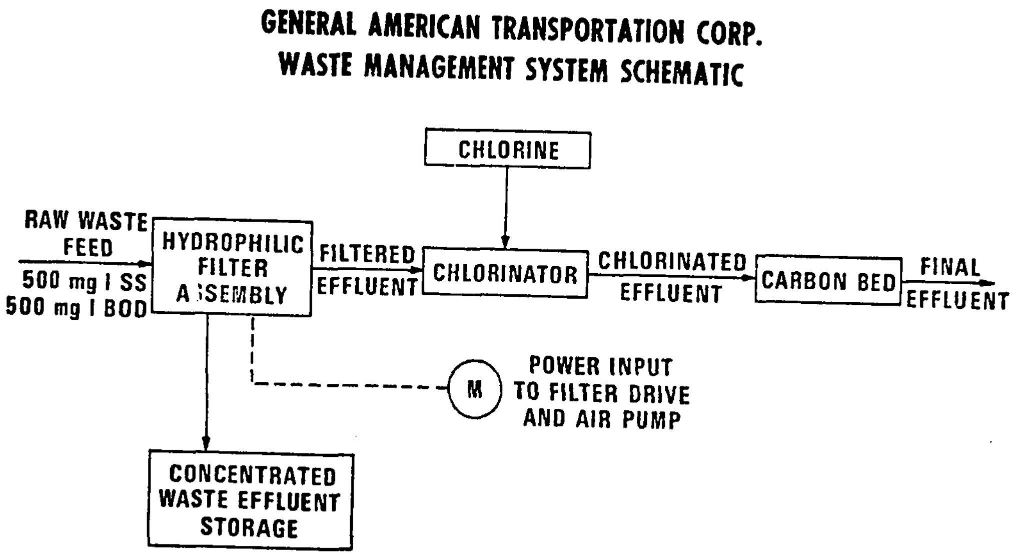

Figure 30. GATX Physical-Chemical System.

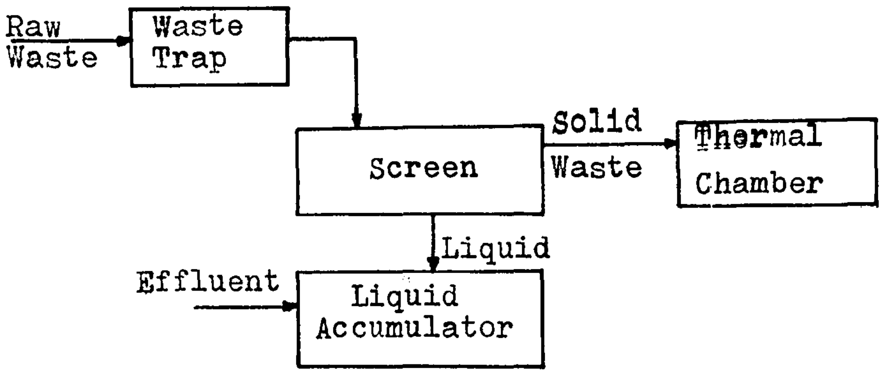

Figure 31 RSC Xpurgator.

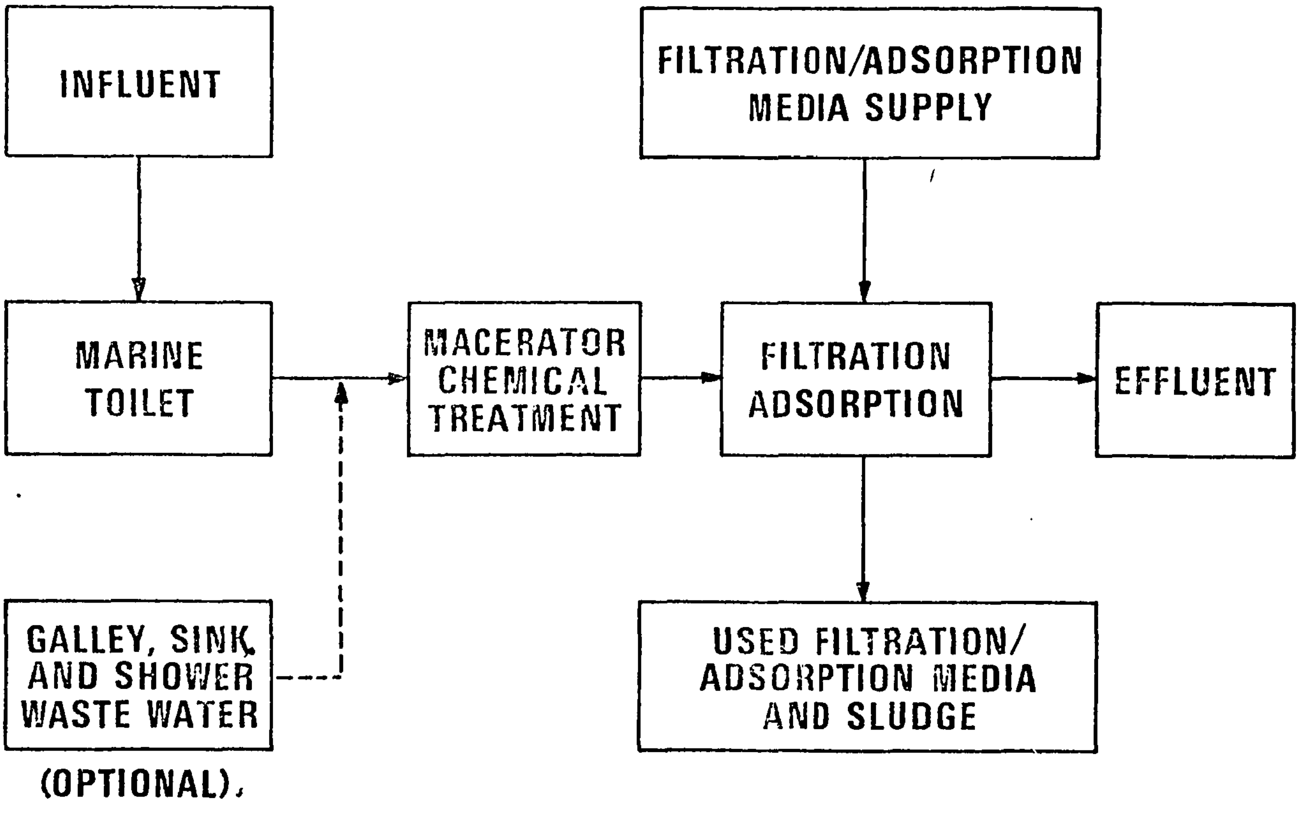

Figure 32. Ametex System.

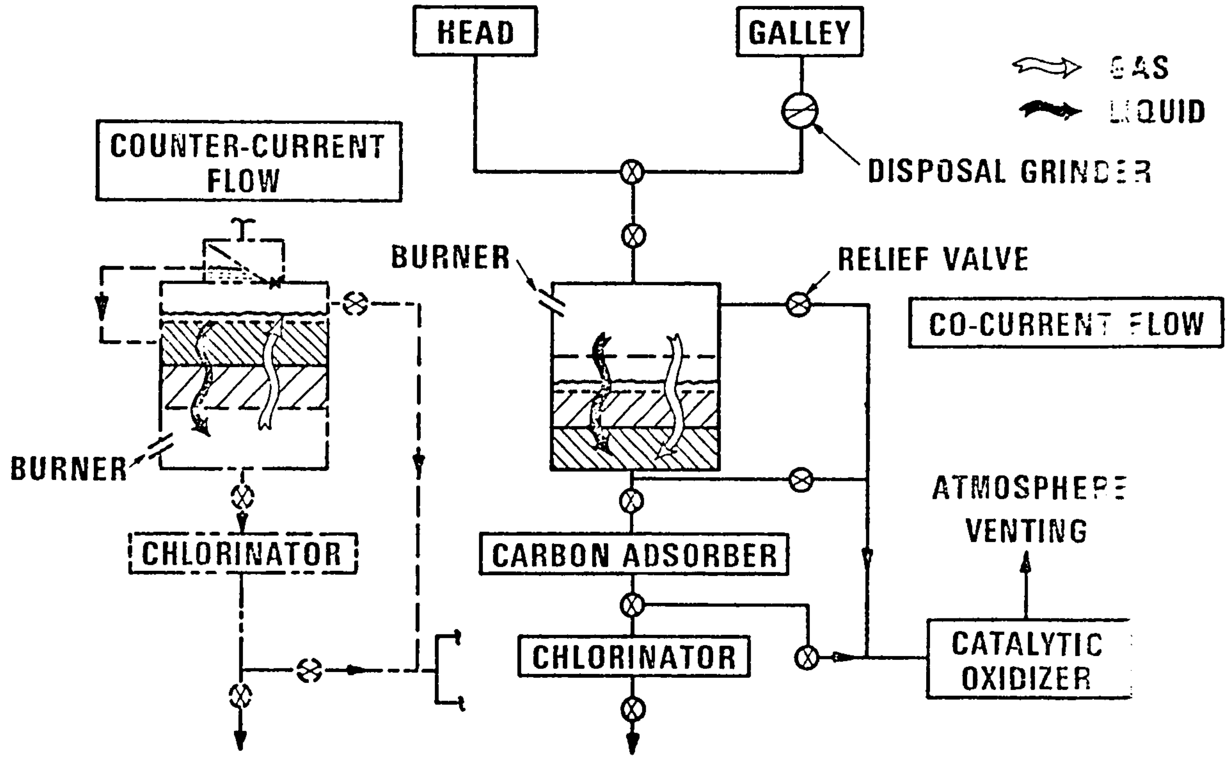

Figure 33. AWT System.

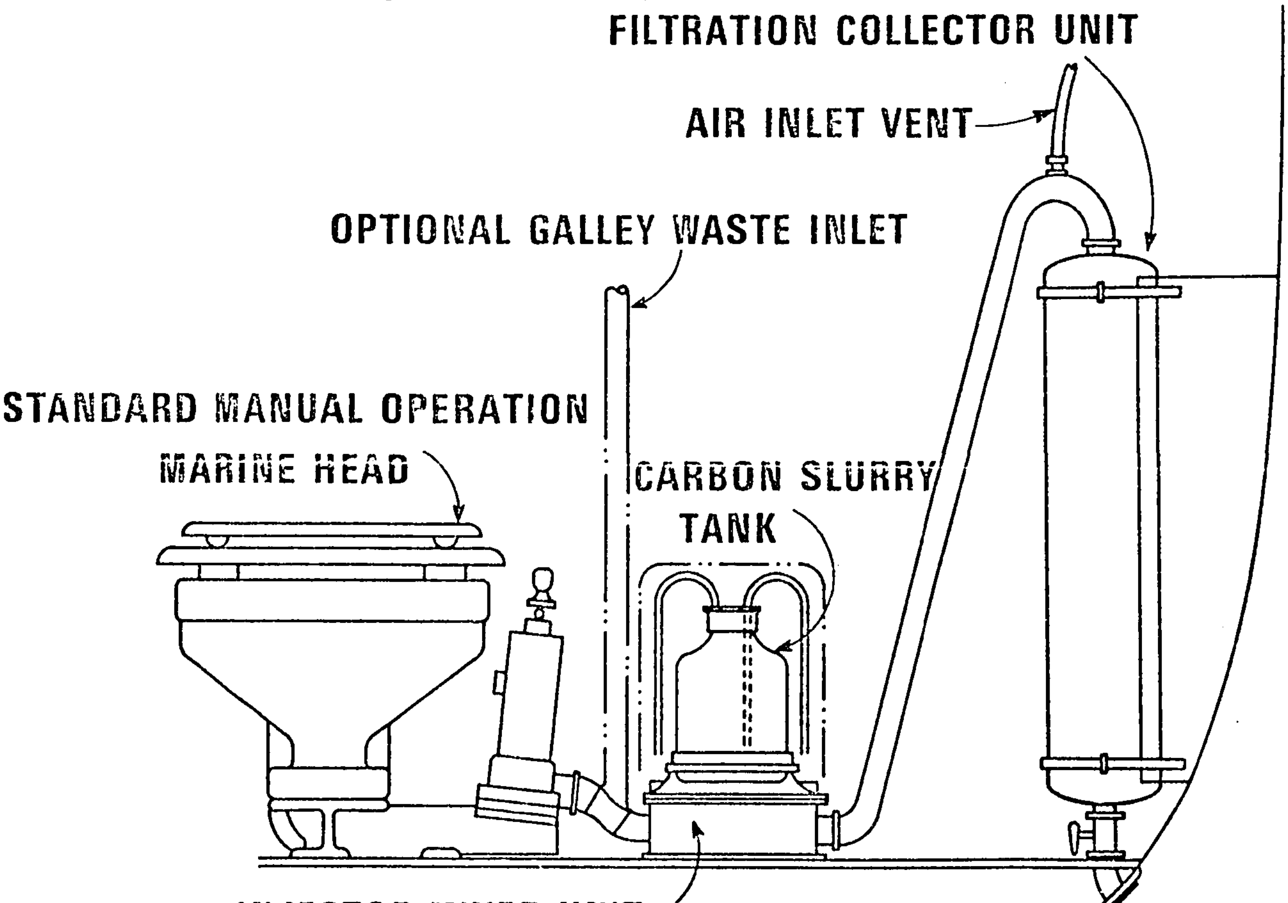

Figure 34. Gulf & Western System.

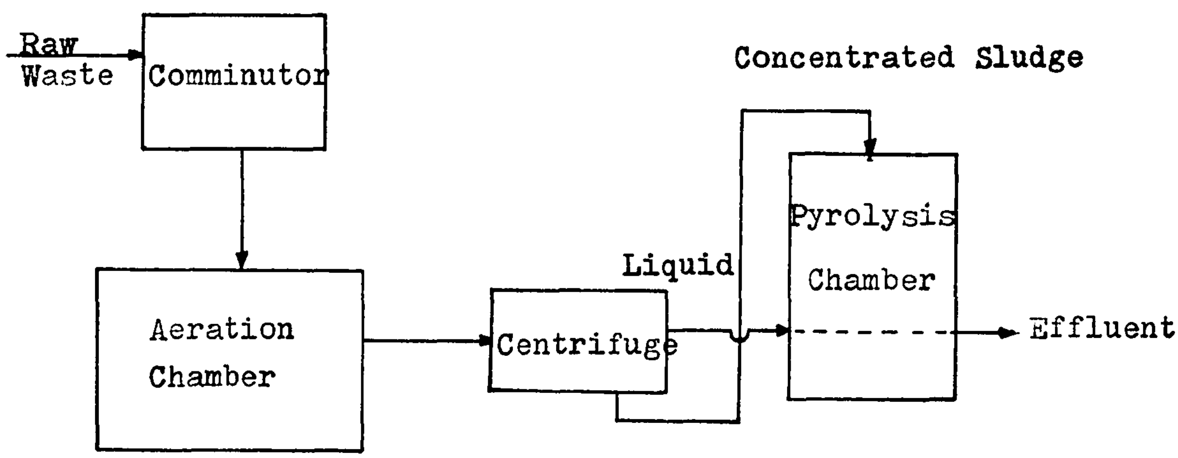

Figure 35. Reid Pyrolysis Aeration System.

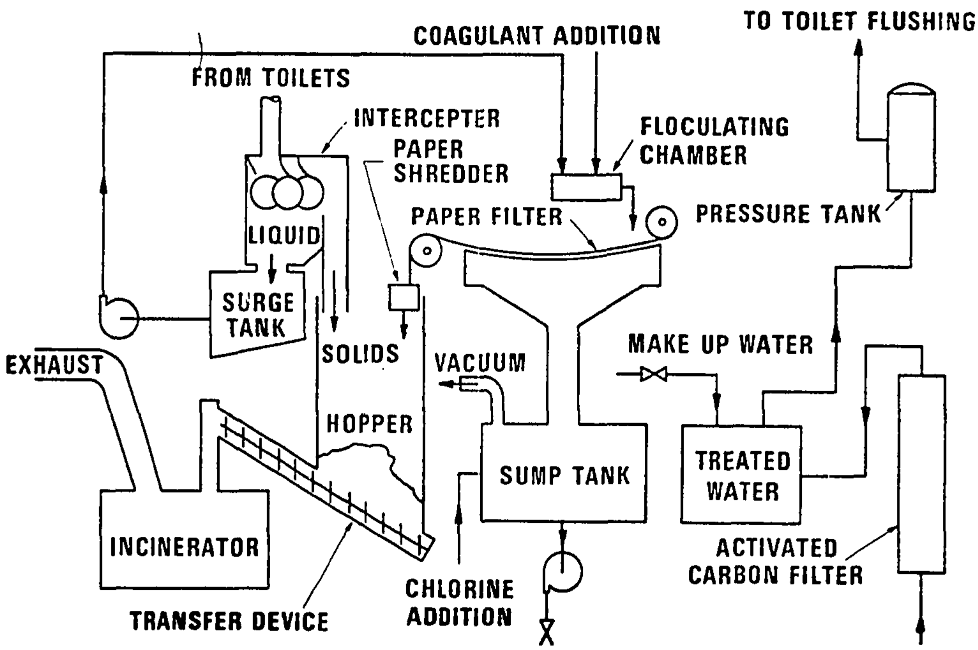

Figure 36. Fairbanks-Morse Toilet Waste Treatment System.

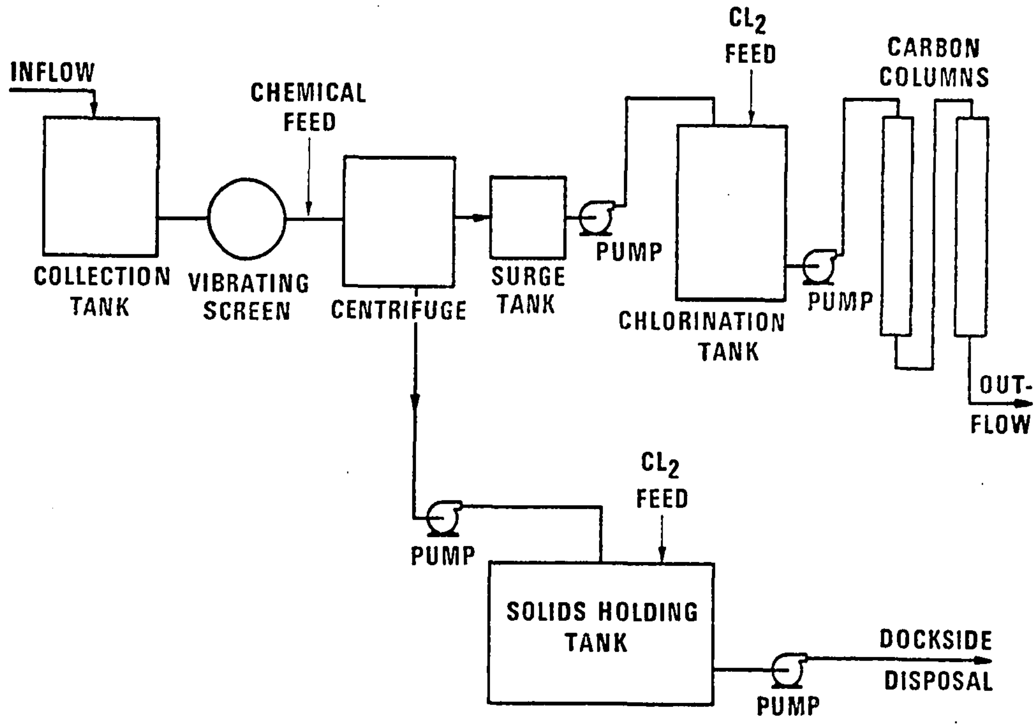

Figure 37. Delaware River & Bay Authority Waste Treatment System.

CHAPTER IV

COST EFFECTIVENESS ANALYSIS

METHODOLOGY

The first characteristic subject to immediate evaluation of onboard sewage treatment devices is the effluent quality produced. However, the effluent quality to meet the regulation is only a single objective that will come from any decision-maker. Other characteristics of the system require analysis to establish a system alternative's overall utility in meeting not just a single objective, but on the entire spectrum of objectives that have been delineated; for instance, the capability of the system to operate continuously and consistantly at design capacity for extended period without failure, the degree of performance influenced by the ship motions, the power, fuel, space, and weight requirements of the system to meet the limitations of shipboard environment, and the concern of safety. These represent only a few of the various delineated system criteria that must be aggregated in such a manner as to reflect the degree that a system alternative is successful in matching the objectives.

Historically, the approach to multi-purpose decision problems has been based on subjective judgement and intuition. Subjective estimates have been used quite frequently to predict probable resources and performance consequences. Personal judgements have been used both to assess the worth of different amount of predicted performance and to affect trade-offs among various worth criteria. In such cases the decision-makers' choices of trade-offs between a system's effectiveness at various levels of performance, problems of interaction between performance criteria and interdependence among such criteria have been confined in the recesses of the decision-maker's mind and, therefore, never subjected to a systematic study to insure explicit, logical consistency which is inherent to a uniformly applicable procedure.

When decisions are rather simple in nature, the subjective process may be the best way to proceed. The extra gains conceivable from systematizing the process would probably not justify the extra effort. However, when the problem becomes even moderative complex, or when the items being selected are poorly understood, or when the consequences of making a poor decision are significant, then heavy reliance on intuition and subjective judgement could invite disaster.

However, the use of a formal, systematic, logical procedure in evaluating the worth of various system alternatives does not necessarily serve to preclude the use of subjective judgement. To the contrary, subjective judgement must be used both in assigning measures of worth to various performance consequences and in trading off worth among various criteria. The purpose is to insure that when subjective judgement is used, it would be made explicit, should be thoroughly examined for logical consistency, and should be elicited by a systematic procedure. The essence of such a procedure is to make what would normally be a subjective decision to some degree more objective by imposing procedural tests for, and bounds on, judgements toinsure that inconsistencies and erroneous assumptions are eliminated.

The framework for evaluating the onboard sewage treatment systems in this study is a decision weighting model which will be used to assess the effectiveness (in measure of worth) of each of the various system alternatives in relation to objectives the system should fulfill.

Decision Weighting Methodology

The evaluation procedure in the decision process is basically a motivating device. It assumes that people in most situations do not make decisions in a strictly rational manner.

The evaluation procedure rests ultimately on concepts of the psychological states of performance, aversion, and indifference. An individual is said to possess a positive preference for some object, activity, or situation if and only if its contemplation or experience elicits a positive emotional feeling, and, conversely, aversion or negative, if and only if its contemplation or experience elicits a negative emotional feeling. An individual is said to be indifferent to object, activity, or situations if and only if he owns neither a preference for it nor an aversion to it.

Preference, aversion, and indifference are nonrational in nature. Yet they do not refer to those cognitive correlates of emotions that are frequently confused with the emotion itself. Thus, justifications, explanations, and reasons for one's feeling must be clearly distinguished from the feeling themselves. That is, a value system should be generated and associated with the decision making process.

Consequently, the concept of worth or utility is defined as conscious perceptions held by the decision-maker relating to his underlying feelings of preference, aversion, and indifference. This includes not only direct awareness of the feeling themselves, but alse the entire rage of cognitive elements supporting such feelings. Conscious rationalizations, justifications, and explanations would all be included within the broad meanings of worth. So the worth of any object or activity inheres in the degree to which it or its consequences are perceived by a given individual in a given situation as satisfying his preferences.

Worth need not be the same or consistent for one or more individuals even under similiar circumstances, since everyone does not have the same experience and knowledge about the system so their preference or aversions may change overtime and according to circumstances.

Therefore, evaluation of worth or utility does not imply simply the measurement of the physical characteristics of an object or activity itself, nor does it imply simply the measurement of the surrounding circumstances, but does imply the investigation of human beings. The decision-maker observes the system objects and activities and considers the existing environmental , social, political, and fiscal circumstances. He formulates the notions of worth, that is, his value system, and projects these notions onto the system objects and activities.

This shows that any evaluation of worth is a subjective process. In order to seek limited objectivity in the sense of "freedom from particular biases", the decision-maker may be asked to follow some reasonable form of limited objectivity to delineate and formulate his preferences relative to specific decision and the system alternatives available. Lack of "complete objectivity" may be the weak point of this concept. Yet "complete objectivity" would require a random selection technique, which could hardly be regarded as luscious to a desision-maker choosing between alternatives. Further, the worth judgements are in principle untestable by ordinary scientific methods. Unlike allegations of facts or empirical predictions, worth judgements are neither true nor false. They simply exist in the minds of indviduals to be accepted or rejected in whole or in part by other individuals. The correctness of a worth judgement can never be demonstrated except by appealing to other worth judgements. Yet the untestable fact does not avert its evaluation over sensitive ranges of values or in terms of a concensus based on informed opinions. Regardless of these speculations, in the final analysis, one cannot repudiate the fact that where alternatives exist, the decision-maker must make a chice. His task is to ensure he assesses all factors in such a manner that the true conceptual worth of all alternatives is revealed. An outline of the procedure follows.

Formulating Procedure

Establishing Overall Objectives

Once a decision context was cited and several meaningful alternative actions have been defined the first step in formulating an evaluation is to specify what is desired. That is listing objectives. These represent the overall performance objectives and are articulated under the following guidelines:

a). The list should be complete and exhaustive. That is, all important performance objectives should be represented on the list. This is to guarantee that no important performance considerations are overlooked by the evaluation procedure.

b). The list should be mutually exclusive, that is, an objective listed should not encompass or be encompassed by any other objectives listed with in whole or in part. This enables the decision-makers to view listed objectives as independent entities among which appropriate trade-offs may later be make and also will prevent undesirable double-counting in the worth sense.

c). The list should be restricted to performance objectives of the highest degree of importance. The purpose is to set a starting basis from which lower-level criteria may be derived.

d). The list should be free of interdependence in the worth sense.

Generating subcriteria

After listing overall performance objectives, the second stage is to describe in more detail what they mean. This is accomplished by a process of repeated conceptual subdivision.

Each objective is divided into one or more lowerlevel criteria and each set of lower-level criteria is set forth to define more precisely what is intended by its higher-level criteria. The process continues until the decision-maker feels that adequate clarification has been achieved.

In general, the lowest-level criteria includes effectiveness criteria, cost criteria, and schedule criteria for an engineering system. An effectiveness criterion is an attribute of a system which is directly related to the fulfillment of needs. A cost criterion is related to the resources required to implement the system alternatives. A schedule criterion is related to the time when the optimal system alternative is needed.

The set of the lowest-level criteria may be partitioned also into subsets of quantified criteria and qualitative criteria. Each element of the set possesses two attributions. One is that the criterion must be measurable, the other is that the measurement is considered to be practical by the decision-maker, that is, the cost and usefulness of its measurement are consistent with achievement of needs and objectives.

Selecting Physical Performance Measure

The third step is to select a single physical performance measure for each lowest-level criterion. By this process, the subjective worth structure of a decision-maker and the objective physical world of alternative are closely related.

When quantitative measures of worth are assigned to various criteria, and situations, great care must be taken in designing the assignment procedure. Relationships between assigned numbers must faithfully réflect perceptions of relative worth.

Formulating Scoring Functions

The fourth step is to establish specific worth relationships between each lowest-level criterion and its associated performance measure. To achieve this, scoring functions are formulated. A scoring function is a mathematical rule that assigns a unique worth score or utility to every possible value of some physical performance measure. It transforms raw performance, measured in terms of whatever physical unit is appropriate to the performance measure under consideration, into worth of performance, measured in terms of the worth scoring or utility. This, in effect, serves to bridge the physical characteristics of the alternative with a worth structure. To insure consistency in the scoring conventions the following ground rules are applicable:

a). The outputs of all scoring functions will be in terms of worth point or utility.

b). Positive numbers will be assigned to situations evaluated as possessing positive worth ,that is. toward which a positive preference is felt.

c). Negative numbers will be assigned to situations evaluated as possessing negative worth, that is, toward which an aversion is felt.

d). The worth scale is bound by plus one and minus one. All real numbers between the range are allowable. Plus one will be used only where complete satisfication is accomplished for the job objective. Conversely, minus one will be used only where nothing worse is logically possible in terms of the stated job. Zero will be assigned to situations toward which indifference is felt.

e). Two situations will be assigned equal worth numbers if and only if they are evaluated as possessing identical worth, that is, a decision-maker feels indifference in choosing between them. A higher worth number will be assigned to situation A rather than situation B if and only if situation A is thought to possess more worth.

f). Situations evaluated as partially successful in accomplishing positive objectives will be assigned according to their proportional or percentage accomplishment of the stated objectives with number between zero and plus one. Conversely, numbers between zero and minus one will be assigned to situations evaluated as partially successful in accomplishing negative objectives according to their proportional or percentage accomplished of stated negative objectives.

g). The entire range of logically physical performance should be covered when formulating the scoring functions. Most scoring functions will be formulated in terms of mathematical formulas and/or graphically characterized mathematical curves. However, some will be assigned without the aid of either formulas or graphs.

h). All scoring functions will be formulated by means of a single, uniform, and replicable procedure. The process is divided into two sequential stages. The first stage contains a series of questions designed to determine the general nature and shape of the functions. The second stage of the scoring process consists of a step-by-step procedure designed to select a particular function of the general nature and shape identified in the first stage. The detail description of the scoring procedure has been presented by J. R. Miller (63).

Assigning Weight

The fifth step in the evaluation procedure is to combine worth scores assigned on the basis of separate performance criteria to a single, overall index of worth. It will be accomplished by defining a weighting function.

A weighting function is a conceptual device that recognize both the existence of multiple objectives and the differential relative importance of satisfying them. At the begining, all the subcriteria subsummed under a given high-level criterion are ranked following the descending perceived importance. Then, starting with the most important pair of subcriteria, successive pairwise comparisons are made between contiguous subcriteria, and decision-maker is asked to indicate the degree of perceived relative importance of the two. A value of one is assigned to the topmost subcriterion, then the second is compared to the first and its importance evaluated in terms of ratio or fraction. The third subcriterion is then compared to the second, and again a relative importance is assigned. For example, assuming that the second were evaluated as being one half as important as the first, while the third were nine-tenths to the second, the appropriate weight would be $\frac{1}{2}$ x 9/10 or 9/20. Successive paired comparisons are quantified in this manner until the list is exhausted. The weight are then summed, each divided by the total, and are reported as normalized weights.

Utility Index

The worth points or utility for each alternative must now be resolved with the adjusted effective weight for each physical measure to derive a utility index. This simply involves multiplying the worth score for each criterion by its corresponding adjusted effective weight for each alternative. The sum of these products is the utility index for the alternative. The alternative with the highest utility index indicates the preferred alternative.

CHAPTER V

PRESENTATION OF FINDING

This chapter deals with the evaluation process. The example presented is for the purpose of showing the procedure in evaluating the currently marketed shipboard sewage disposal systems which will best meet the efficient and economical requirements of a shipboard waste treatment system. It also serves as the illustration of the detailed computations so that further analysis of all alternatives can be computerized. Only the applicable final utilities of the alternatives are reported.

Objective or Criteria Hierarchy

Four principal objectives are established as the highest level performance criteria. The decomposition of each of those criteria are addressed in the following paragraphs.

Compatibility with Shipboard Environment

Although margins are always provided in the design of vessels to permit some increase in weight during development of detailed working plans resulting from incorporation of new features and a higher center of gravity than estimated, an ideal shipboard waste treatment device must be equipped with minimum space and weight requirements so that it can be easily installed on board and the finished ship will still have proper displacement and stability.

As ship safety is concerned, it is important to eliminate the potential of hazard from the shipboard sewage treatment devices. Hazards include the acceleration and motion hazard, oxidation, contamination, and corrosion hazard, electrical, shock, thermal, and system failure hazard, explosion hazard, fire hazard, heat, temperature, and tempertaure change hazard, system leakage hazard, power source failure hazard, pressure and pressure change hazard, radiation hazard, toxicity hazard, and vibration and noise hazard. In order to check the system's safety, certain questions have to be asked: Are the systems safe in operation? Are they equipped with enough safeguards? Are the systems equipped with dangerous characteristics or are dangerous energy levels present or does the system require certain toxic materials for operation?

Habitability considerations demand that the equipment be operated with a minimum of noise, heat, vibration, odor, and other air pollution.

The compatibility with shipboard environment is broken down to include space requirement, safety, and esthetic effect. Both space and weight requirements will be evaluated with the manufactuer supported data, whereas the safety and esthetic effect will be assessed by examining the schematic characteristics of each alternative.

Environmental Quality Control

The first consideration for a shipboard sewage treatment device is technologically that the system has the ability to produce an effluent that complies with present and possibly near future state, federal, and international established regulations and standards.

The environmental quality control is broken to include discharged effluent quality, time required to reach the designed performance after each start, and the potential to meet the future no-discharge regulation.

Discharged effluent quality will be measured by reviewing the manufacturer supported effluent quality data, whereas both the potential to meet the future no-discharge regulations and time required to reach the designed performance after each start can only be accomplished by examining the system schematic characteristics of each alternative.

Simplicity of Operation

As mentioned earlier, as a vessel leaves port it is a self-contained unit; equipment must be operated by the limited manpower and any equipment failure must be corrected by the crew with on-board tools and spare parts. Specilists in the care of certain equipment are unavailable, Although ship crews are well trained and ingenious mechanics they can not be totally familiar with all details of the multiplicity of shipboard equipment. For this reason it is important that any shipboard waste treatment system should be so designed that it can be operated by a crew member with limited supervision, and the increased workload imposed on operating personnel by installing a treatment plant on-board should not disturb or disturb only to a minimum extent the vessel's mission such as commercial or recreational activity.

The simplicity of operation is delineated into the following lower-level subcriteria; degree of automation, shoreside facilities dependency, supervision hours required per week, and specialist dependency. The degree of automation will be estimated directly for each alternative by examining its control system. Shoreside facilities dependency is further decomposed into frequency of shoreside service required per week; ease of shoreside cleaning, maintenamce; and pumping hours required. Supervision hours required per week will include the manufacturer's recommended routine check such as visual inspection of the equipment condition and operation, metering pump check, oil level check, moving parts lubrication, and consumable chemicals feeding, etc. Specialist dependency will be obtained by judging the system schematic characteristics.

Reliability

Reliability is the ability of equipment to preserve its output characteristics within established limits under given operating conditions. It shows the probability that a device will operate without failures for a given time under given operating conditions.

Quantitatively, the reliability of a system depends on the quantity and quality of its components, on the operating conditions of the components, and the as-built adequancy. The reliability of components of a system depends, in turn, on the technology of production, the quality of materials, and other things.

An ideal shipboard sewage treatment device should provide a high degree of reliability and be capable of operating continuously at design capacity for extended periods. Any failure should not be allowed to occur that would require the ship to return to port. Ability of a system to consistently produce the desired effluent quality under a variety of hydraulic loadings, waste characteristics, ship motions, sea water flushing, influent toxic chemicals, and temperature extremes are in this category. Since there is no such data provided by the manufacturer, a direct estimation based on judgement among the following views will be assesses;

(1). Examining the moving parts of the system and the operating conditions under which the moving parts are operated,

(2). Examining the schematic characteristics of the system and considering the system in relation to shipboard operating conditions, and

(3). Examining the construction materials and considering them in relation to the shipboard environment.

Reliability will then be decomposed into three lower-level criteria, namely, possibility of parts failure, sensitivity to ambient change, and sensitivity to raw material change.

Formulation of Scoring Functions

Of the sixteen performance measures in Figure 38, only six are defined in such a manner as to require explicit graphical

Figure 38. Criteria Hierarchy.

TOTAL WORTH	Compatibility with Shipboard Environment	Space Requirement		ft^3/man
		Weight Requirement		lbs/man
		Safety Consideration		D.E.
		Habitability Consideration		D.E.
	Simplicity of Operation	Shoreside facility Dependency	Ease of Cleaning, maintenance, repairing.	D.E.
			Pumping hours Required	hours
			Frequency of Shoreside service Required.	times/week
		Degree of Automation		D.E.
		Supervision hours Required		hours/week
		Specialist Dependency		D.E.
	Environmental Quality Control	Effluent Quality		BOD,SS,Coli.
		Time Required to Reach the designed performance after each start		D.E.
		Potential to meet the future no-discharge requirement		D.E.
	Reliability	Possibility of parts in malfunction		D.E.
		Sensitivity to ambient change		D.E.
		Sensitivity to raw material change		D.E.

scoring functions, and the remaining ten are evaluated and articulated as direct estimates.

Before the final establishment of the graphical scoring functions, a questionnaire (see Appendex 2) has been utilized as a means to collect the opinions of ship operators, ship manufacturers, and ship owners on what a shipboard waste disposal device should have in order to be installed aboard. Most of the samples are selected randomly from Poor's Register. The returned questionnaires include: four from the Corps of Engineers, two from the Department of the Navy, and seventeen from commercial vessel operators. Explicit graphical scoring functions are obtained by averaging those values in the returned questionnaires and are summarized in Figures 39-a, 39-b, 39-c, 39-d, and 39-e.

Direct Estimate Scoring Functions

Assignment of worth scores for those criteria requiring direct estimates has been assessed for every alternative. The results are summarized in Table 8. In order to show the process of direct estimate, the evaluation of General Electric System is described in Table 9.

In this stage of evaluation, two major operations are involved. In the first step of operation, all alternatives are ranked in order of descending perceived effectiveness to a specific criterion which requires direct estimate. Then, starting with the most effective pair of alternatives appearing at the head of the list, successive pairwise comparisons are made

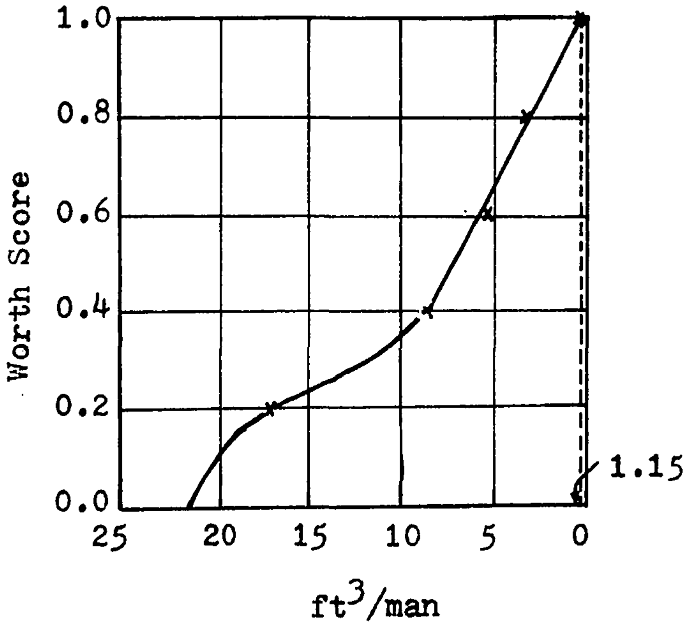

Figure 39-a. Space Requirement Scoring Function.

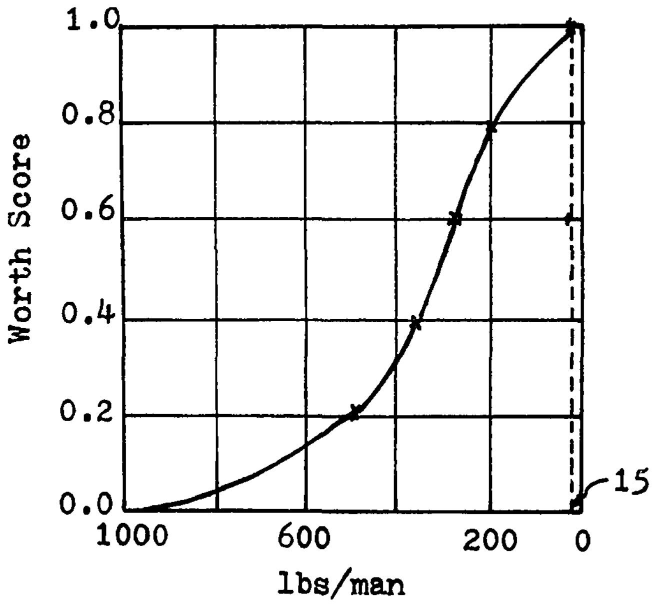

Figure 39-b. Weight Requirement Scoring Function.

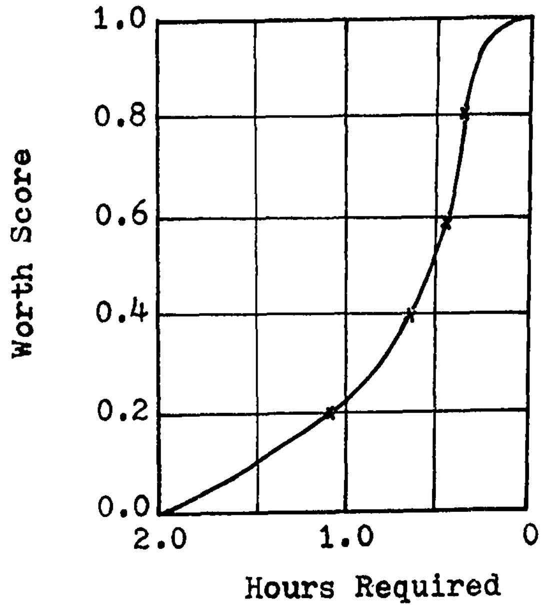

Figure 39-c. Pumping Hours Required Scoring Function.

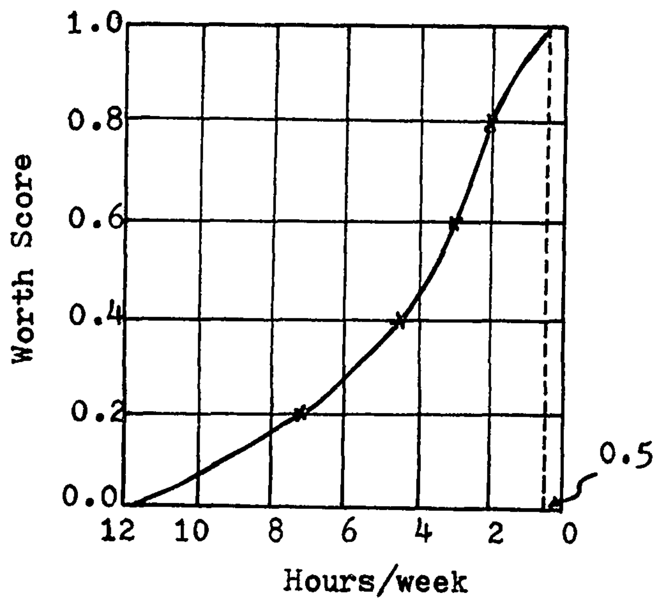

Figure 39-d. Supervision Hours Required Scoring Function.

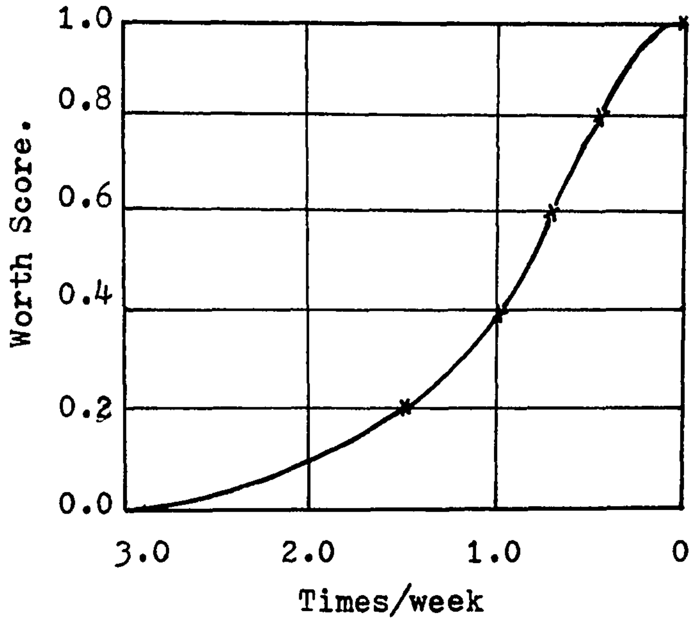

Figure 39-e. Frequency of Shoreside Service Scoring Function.

Table 8. Performance/Worth Score.

Performance Measure / Alternative		A*	B*	C*	D*	E*	F*	G*	H*	I*	J*	K*	L*	M*	N*	O*	P*
Jered VACU-BURN		.97	.97	.81	.82	.87	1.0	1.0	.98	.60	.96	1.0	.98	1.0	.84	.94	1.0
Chrysler System Aqua-Sams	A	.77	.96	.89	.86	.79	1.0	1.0	.98	.80	.92	1.0	1.0	1.0	.83	.87	.96
	A-1	.89	.98	.89	.86	.79	1.0	1.0	.98	.80	.92	1.0	1.0	1.0	.83	.87	.96
	B	.96	.99	.89	.86	.79	1.0	1.0	.98	.80	.92	1.0	1.0	1.0	.83	.87	.96
	C	.97	1.0	.89	.86	.79	1.0	1.0	.98	.80	.92	1.0	1.0	1.0	.83	.87	.96
Colt's M175CM		1.0	.98	.70	.74	.85	1.0	1.0	.96	.80	.87	.89	.97	.86	.91	.90	.87
M5000CM		.95	.98	.70	.74	.85	1.0	1.0	.96	.80	.87	.89	.97	.86	.91	.90	.87
Enviro-VAC		.60	.70	.91	.93	.93	.05	.40	.96	.96	.98	1.0	1.0	1.0	.84	.94	1.0
GATX ETS-125		.94	.98	.92	.80	.91	.56	.92	.99	.96	.95	1.0	1.0	1.0	.95	1.0	1.0
Thiokol MPB-10		.81	.98	.80	.84	.75	1.0	1.0	.78	.52	.90	.96	1.0	.93	.93	1.0	1.0
Thiokol Navy System		.83	.95	.79	.80	.83	1.0	1.0	.96	.89	.85	.96	1.0	.90	.92	.98	1.0
St.Louis Ship FAST-15		.00	.04	.96	.94	.88	.23	1.0	.95	.23	.94	1.0	1.0	1.0	.93	1.0	.97
Lundy UF-5		.23	.57	.84	.85	.90	.40	.40	.98	.46	.93	.98	1.0	.96	.91	.94	1.0
Ocean System Model		1.0	.99	.79	.76	.88	1.0	1.0	.97	1.0	1.0	1.0	1.0	1.0	.94	.95	1.0
Westinghouse System		.99	.97	.80	.80	.81	1.0	1.0	.98	.96	.94	1.0	1.0	1.0	.92	.99	1.0
Koehler-Dayton MSTS		1.0	1.0	.86	.80	.83	1.0	1.0	.97	.80	.97	1.0	1.0	1.0	.98	1.0	1.0

Table 8. (Cont'd)

Alternative	Performance Measure	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Seapax System	20	.78	.89	.82	.83	.89	.35	.76	.93	.71	.97	1.0	.95	1.0	.86	.91	.99
	50	.90	.95	.82	.83	.89	.35	.76	.93	.71	.97	1.0	.95	1.0	.86	.91	.99
	100	.95	.97	.82	.83	.89	.05	.76	.93	.71	.97	1.0	.95	1.0	.86	.91	.99
FMC MSD	50-2000	.92	.98	.96	.83	.80	1.0	.85	.94	.60	.82	.97	.95	.94	.82	.91	.95
	50-3000	1.0	1.0	.91	.83	.80	1.0	.85	.94	.60	.82	.97	.95	.94	.82	.91	.95
	50-4000	.98	.99	.91	.83	.80	1.0	.85	.94	.60	.82	.97	.95	.94	.82	.91	.95
	50-8000	.88	.98	.91	.83	.80	1.0	.85	.94	.60	.82	.97	.95	.94	.82	.91	.95
Hyde System		.70	.82	.96	.95	.86	1.0	.94	.95	.96	.89	.92	.97	.82	.84	.98	.98
Grumman Ozotherm	1500gpd	.94	.98	.76	.80	.84	1.0	1.0	.89	.82	.86	.97	.94	.92	.87	.96	.98
	5000gpd	.90	.98	.76	.80	.84	1.0	1.0	.89	.82	.86	.97	.94	.92	.87	.96	.98
	25000gpd	.87	.99	.76	.80	.84	1.0	1.0	.89	.82	.86	.97	.94	.92	.87	.96	.98
Wilson's MACL	1500gpd	1.0	.97	.81	.65	.73	1.0	1.0	.94	.80	.98	0.0	.96	0.0	.80	1.0	1.0
	2500gpd	1.0	.97	.81	.65	.73	1.0	1.0	.94	.80	.98	0.0	.96	0.0	.80	1.0	1.0
	5000gpd	1.0	.98	.81	.65	.73	1.0	1.0	.94	.80	.98	0.0	.96	0.0	.80	1.0	1.0
General Electric SWTS		.68	.94	.68	.82	.70	1.0	1.0	.90	.96	.82	.82	.90	.92	.90	.81	.88
Babcock & Wilcox Mkja		.34	.35	.93	.94	.89	1.0	1.0	.96	1.0	.96	1.0	1.0	1.0	.95	1.0	1.0
Fram (SP-75)		.67	.86	.89	.86	.88	1.0	1.0	.99	.70	.97	.96	.77	.81	.93	.86	.88

Table 8. (Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Incinolet	1.0	1.0	.74	.79	.94	1.0	1.0	.97	1.0	.99	1.0	1.0	1.0	.85	.92	1.0
Destroilet	1.0	1.0	.61	.74	.96	1.0	1.0	.99	1.0	.99	1.0	1.0	1.0	.90	.95	1.0
Wilcox-Crittenden Holding Tank	1.0	.97	.89	.72	.65	1.0	0.0	.75	1.0	1.0	1.0	1.0	1.0	.94	.95	.98
Monogram Jet-O-Matic	1.0	.99	.96	.92	.95	.82	.26	.98	.96	.99	1.0	1.0	1.0	.98	.98	.99
Newmatic	1.0	.99	.96	.92	.95	.82	.26	.98	.96	.99	1.0	1.0	1.0	.98	.98	.99
Firestone Marine Tank	1.0	1.0	.94	.87	.89	.55	0.0	.86	.96	1.0	1.0	1.0	1.0	.82	.92	.87
Sea Farer	1.0	1.0	.98	.94	.82	1.0	0.0	.94	1.0	.99	1.0	1.0	1.0	.96	.90	.96
Electra Magic	1.0	1.0	.98	.94	.82	1.0	0.0	.97	1.0	.99	1.0	1.0	1.0	.96	.94	.98
Aqua Magic	1.0	1.0	.98	.96	.81	1.0	0.0	.94	1.0	.99	1.0	1.0	1.0	.97	.96	.98
Porta Potti	1.0	1.0	.97	.97	.80	1.0	0.0	.96	1.0	.99	1.0	1.0	1.0	.97	.96	.98
Mansfield Vacuum Flush	1.0	.97	.91	.86	.89	.55	.26	.89	1.0	.92	1.0	.99	1.0	.85	.93	.98
Aquatic Designs Holding Tank	1.0	.98	.89	.72	.64	1.0	.40	.75	1.0	.99	1.0	1.0	1.0	.94	.94	.98
Jonny Trap JT 12	1.0	.98	.89	.72	.62	1.0	0.0	.72	1.0	.99	1.0	1.0	1.0	.95	.96	.98
Potpourri	1.0	1.0	.93	.86	.91	1.0	.19	.87	.96	.98	1.0	1.0	1.0	.96	.96	1.0
Kracor Holding Tank	1.0	.97	.93	.87	.89	.82	.26	.87	1.0	.98	1.0	1.0	1.0	.97	.98	.96

Table 8. (Cont'd)

Performance Measure / Alternative		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Jensen Model 770		1.0	.99	.93	.92	.93	.82	.26	.92	1.0	.98	1.0	1.0	1.0	.97	.98	.96
Bio-Pure	BP 6D	.24	.13	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP12D	.25	.20	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP20D	.30	.37	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP30D	.28	.34	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP50-D	.30	.36	.96	.89	.85	1.0	1.0	0.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP75D	.33	.44	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
	BP100D	.57	.46	.96	.89	.85	1.0	1.0	.96	.80	.87	.65	.40	.23	.82	.69	.62
Red Fox RF3000M		.18	.13	.93	.80	.87	1.0	1.0	.86	.98	.94	.95	.23	.30	.78	.65	.59
Demco	WT2200C	.40	.15	.95	.82	.85	1.0	1.0	.96	.89	.86	.94	.52	.23	.80	.70	.64
	WT325	.25	.05	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT625	.32	.08	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT1000	.33	.10	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT1250	.38	.13	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT1565	.37	.14	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT1875	.43	.16	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT2500	.43	.17	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.79	.64

Table 8. (cont'd)

Alternative	Performance Measure	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Demco	WT2815	.44	.18	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT3125	.44	.20	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT3750	.40	.17	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT5000	.44	.20	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT6000	.42	.20	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT7000	.43	.20	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT8000	.47	.23	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT9000	.48	.23	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT10000	.47	.23	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
	WT12500	.45	.20	.95	.82	.85	1.0	1.0	.96	.89	.96	.94	.52	.23	.80	.70	.64
Weldco		.65	.89	.95	.68	.92	1.0	1.0	.96	.89	.96	0.0	.23	0.0	.97	.62	.55
IWC M5000		.72	.94	.95	.92	.92	1.0	1.0	.97	.23	.98	.95	.42	.56	.95	.65	.60
Bio-Flo		.98	.76	.84	.88	.86	1.0	1.0	.79	.80	.82	.60	.70	.30	.79	.62	.59
Microphor	M-10	.99	.99	.96	.59	.92	1.0	1.0	.65	.96	.98	0.0	.12	.00	.65	.49	.42
	M12	.96	.97	.96	.59	.92	1.0	1.0	.65	.96	.98	.00	.12	.00	.65	.49	.42

Table 8. (Contd)

* A: Space Requirement

B: Weight Requirement

C: Safety Consideration

D: Habitability Consideration

E: Ease of Cleaning, Maintenance, Repairing

F: Pumping Hours Required

G: Frequency of Shoreside Service

H. Degree of Automation

I: Supervision Hours Required

J: Specialist Dependency

K: Effluent Quality

L: Time Required to Reach the Designed Performance

M: Potential to meet the future no-discharge Requirement

N: Possibility of Parts in Malfunction

O: Sensitivity to the Ambient Changes

P: Sensitivity to the Raw Material Changes.

Table 9. Example for Direct Estimate Scoring Functions
(General Electric Marine Waste Disposal System)

Performance Criteria	Worth Score	Evaluation Background
Safety Effect	0.68	a). The generation of hydrogen gas and chlorine gas from the electrolysis reactions contribute to the explosion, corrosion and toxicity hazard. b). Fire operated incineration and high temperature (up to $1500^{\circ}F$) deodorization increase the fire, heat, and high temperature hazard. c). Sewage gas produced from the anaerobic condition in sludge blanket and concentrator enhence the explosion hazard.
Habitability Consideration	0.82	Presence of hydrogen gas, chlorine gas, sewage gas, and emision and particulates from the incinerator creat the odor and other air pollution problems.
Cleaning, Maintenance, and Repairing	0.70	a). Electro cell has to be cleaned by air flush or acid flush to remove deposited solids. b). Mild steel plates of electro cell have to be replaced after 600 hours operation. c). At 340 hours of operation, it is necessary to replace the the lower bushing of the central downcomer stirrer due to binding. d). At 1500 hours of operation, replacement of the synthetic rubber stator of the Moyno progressive-cavity pump is required. e). At 2 months of operation, activated carbon column requires to be replaced. f). Inorganic ash has to be removed from the incinerator every two weeks. g). Consumable goods, such as coagulants, chlorine, etc. have to be replenshed frequently. h). pH has to be controlled at approximately 9.

Table 9. (Cont'd)

Performance Criteria	Worth Score	Evaluation Background
Degree of Automation	0.90	a). System consists of six major unit processes and several chemical feeding units.(not simple in the sense). b). No suitable measuring (feedback) element exists in the control system. Sodium Aluminate flocculant aid, and hypochlorite solution are fed to the system by using single-acting agjustable disphram types of pumps. Feeding rates are based on primary calibration. Loss of initial calibration is incurred due to crystal build up on the check valve. There is no way for the control device to response to thesystem variables change automatically. c). pH controller is not available.
Specialist Dependency	0.82	a). The hydrodynamic stability of the upflow clarifier requires special care. The balance of influent versus effluent and sludge withdrawal rate in the clarifier is critical. b). System involves electrolysis technique that requires specially trained personnel. c). Discharge of hygrogen gas, chlorine gas, and sewage gas require special care. d). Inspection of pH value in the electrolysis cell is demanded.
Time Required to Reach the designed performance	0.90	a). It takes a period of time to reach hydrodynamically stable in the clarifier. b). It takes a period of time for Fe^{II} to reach 70 ppm in the electrolysis cell.
Potential to meet the no-discharge Requirement	0.92	a). System has partial removal on dissolved organic. b). Suspended solids removal is not consistant in the clarifier. c). Sepeticity in the carbon column may add to the high BOD and SS values in the effluent stream.
Critical parts	0.90	a). System consists of one pump grinder, one electrolysis cell, one clarifier, one set of carbon column, one incinerator, one chlorinator, two sludge holding tanks, one emergency pump, one discharge pump, two blowers, three sludge

Table 9. (Cont'd)

Performance Criteria	Worth Score		Evaluation Background
Critical part in malfunction			withdrawal pumps, two chemical feeding pumps and others.
		b).	Activeted carbon column has tendency to become septic and clogged, check valves have the tendency to build up crystal, electro cell has thetendency to build up solids, central downcomer stirrer may be bound, etc.
Sensitivity to Ambient Change	0.81	a).	Electrolysis is sensitive to temperature change.
		b).	Clarification and sludge blanket are sensitive to ship motions, machinery vibration.
Sensitivity to Raw Material Changes	0.88	a).	Performance of electro cell is sensitive to solids loading.
		b).	Sludge blanket is sensitive to hydraulic loading and solids loading.

between contiguous alternatives, and decision-maker is asked to indicate in terms of ratio the degree of perceived relative effectiveness of the two. For example, under the criterion of potential to meet the future no-discharge requirement, systems which are capable of retaining the wastes on-board and/or are designed to reuse the treated effluent on-board are polled on the head of the list and are assigned one to their worth scores, whereas those which produce the secondary effluent and discharge the treated effluent overboard are ranked according to their system schematic characteristics, such as, the ability of the system to remove the pollutants, and further treatment processes required in order to make the system a complete closed system.

Follow this, the second step of operation is conducted to obtain the worth scores for every alternative.

Formulating the Weighting Functions

The numerical weights are then assigned to subcriteria at every branching point in the hierarchy. Values of these weighting functions are obtained by averaging the returned questionnaires as described in Appendix 2. They are summarized as follows:

For the overall criteria, values are as follow:

Ranked-Ordered Objectives	Normalized Weighting Factors
Environmental Quality Control	0.32
Reliability	0.30

Ranked-Ordered Objectives	Normalized Weighting Factors
Compatibility with the Shipboard Environment	0.23
Simplicity of Operation	0.15
Total	1.00

Within Environment Quality Control, weights are as follows:

Ranker-Ordered Objectives	Normalized Weighting Factors
Potential to meet the future no-discharge Requirement	0.40
Time required to Reach the Designed Performance	0.34
Effluent Quality	0.26
Total	1.00

Within Reliability, weights are as follows:

Ranked-Ordered Objectives	Normalized Weighting Factors
Critical Parts in Malfunction	0.37
Sensitivity to Ambient Change	0.32
Sensitivity to Raw Material Change	0.31
Total	1.00

Within the Compatibility with Shipboard Environment, weights are as follows:

Ranker-Ordered Objectives	Normalized Weighting Factors
Space Requirement	0.34
Safety Consideration	0.31
Weight Requirement	0.20
Esthetic Effect	0.15
Total	1.00

Within the Simplicity of Operation, weights are as follows:

Ranked-Ordered Objectives	Normalized Weighting Factors
Supervision hours Required per Week	0.32
Specialist Dependency	0.26
Shore-side Facilities Dependency	0.24
Degree of Automation	0.18
Total	1.00

Within the Shore-side Facilities Dependency, weights are as follows:

Ranked-Ordered Objectives	Normalized Weighting Factors
Frequency of Shore-side Service	0.37
Ease of Cleaning, Maintenance, Repairing	0.36
Pumping Hours Required	0.27
Total	1.00

The above assignment of weights lead to the following distribution of effective weights on each of the sixteen lowest-level performance criteria.

Table 10. Effective Weight

Performance Criteria	Effective Weight
Space Requirement	0.078
Weight Requirement	0.046
Safety	0.071
Esthetic Effect	0.035
Ease of Cleaning, Maintenance, Repairing	0.013
Pumping Hours Required	0.010
Frequency of Shoreside Service	0.013
Degree of Automation	0.027
Supervision Required per week	0.048
Specialist Dependency	0.039
Effluent Quality	0.083
Time to Reach Steady State	0.109
Potential to meet No-Discharge	0.128
Critical parts in Malfunction	0.111
Sensitivity to Ambient Change	0.096
Sensitivity to Raw Material Change	0.093
Total	1.000

The weighting factors for the lower-level criteria and the respective performance measures are now subjected to the adjustment. As noted previously, the adjusting factor seeks to reflect the effectiveness of the performance measure to interpret the meaning of the associated criterion. For example, the effluent quality is regarded by the writer to be 100 % successful in interpreting the meaning of the ability of equipment to produce certain quality of water, whereas the degree of automation may be regarded as somewhat arbitrary and its value to interpret the criterion's meaning should be degraded .The writer choose to attach 96 % as an adjusting factor for the degree of automation. Detailed description of the rational for each adjusting factor is summarized in Table 11. The original effective weight, the adjusting factors, and the final set of adjusting effective weights are shown below in Table 12.

Total Utility for Alternatives

The final utilities can now be formulated by multiplying the criterion scores by their adjusted effective weights and adding the products to determine each alternative's total worth score. The results are summarized in Table 13.

Table 11. Adjusting Factors

Performance Criteria	Adjusting Factors	Evaluation Background
Space Requirement	0.87	a).Installation is not considered in this interpretation. b).Working space is not included. c).Space required to keep the consumable goods is not included.
Weight Requirement	0.94	a).Weight requirement for keeping the consumable goods is not considered. b).Installation is not considered.
Safety Consideration	0.79	a).Quantitative data are not available to support this measurement. b).Information on the equipped safeguard and the technique to keep the dangerous materials are usually not available. c).Insulation and venting systems are only lightly considered.
Habitability Consideration	0.86	a).Venting and Insulation systems are lightly considered.
Ease of Cleaning, Maintenance, Repairing	0.82	a).Consumables inventory is only lightly considered. b).It is assumed that repair parts are available on market. c).Time required to replace parts is not considered.
Pumping hours Required	1.00	
Frequency of Shoreside Service.	1.00	

Table 11. (Cont'd)

Performance Criteria	Adjusting Factors	Evaluation Background
Degree of Automation	0.96	a).Systems are evaluated by comparing the procedure for manual operation only.
Supervision	1.00	
Specialist Dependency	0.89	a).The knowledge level of the shipboard sewage treatment system's operating personnel is not investigated.
Effluent Quality	1.00	
Time required to Reach the designed performance	0.90	a).The data which describe the system's response during the unsteady state are not available. b).It is considered only by examining the system schematic characteristics.
Potential to meet the future no-discharge requirement	0.92	a).Systems are evaluated by reviewing the system schematic characteristics only, such as, the ability of the systems to remove the pollutants, and further treatment processes required in order to make the system a complete closed system.
Possibility of parts in malfunction	0.69	a). The quantitative data are not available.
Sensitivity to Ambient Change	0.82	a).Quantitative data are not available. Yet it can be evaluated by examining the system schematic characteristics.
Sensitivity to raw material change	0.87	a).Systems are evaluated by examining the schematic characteristics.

Table 12. Effective Weights, Adjusting factors, and Adjusted Effective Weights.

Performance Criteria(1)	Effective Weights(2)	Adjusting Factors	(2)x(3)	Adjusted Effective Weights
Space Requirement	.078	.87	.0608	.070
Weight Requirement	.046	.94	.0432	.049
Safety	.071	.79	.0560	.065
Habitability	.035	.86	.0301	.0347
Cleaning,Mainten-ance,Repairing.	.013	.82	.0107	.012
Pumping Hours	.010	1.0	.010	.012
Frequency of Shore-side service	.013	1.0	.013	.015
Degree of Automation	.027	.96	.0259	.030
Supervision Hours	.048	1.0	.048	.055
Specialist Depen-dency	.039	.89	.0347	.040
Effluent Quality	.083	1.0	.083	.096
Time to Reach Designed Performance	.109	.90	.0981	.113
Potential to meet n no-Discharge	.128	.92	.118	.136
Parts in Mal-function	.111	.69	.077	.089
Sensitivity to Ambient Change	.096	.82	.079	.091
Sensitivity to Raw Material Change	.093	.87	.0809	.093

Table 13. Total Worth Scores.

Performance Measure / Alternative	A*	B*	C*	D*	E*	F*	G*	H*	I*	J*	K*	L*	M*	N*	O*	P*	Total Worth
Jered VACU-BURN system	.0679	.0475	.0527	.0285	.0104	.0120	.0150	.0294	.0330	.0384	.0960	.1110	.1360	.0748	.0855	.0930	.9311
Chrysler Aqua-Sams A	.0539	.0470	.0579	.0289	.0095	.0120	.0150	.0294	.0440	.0368	.0960	.1130	.1360	.0739	.0792	.0893	.9227
A-1	.0623	.0480	.0579	.0289	.0095	.0120	.0150	.0294	.0440	.0368	.0960	.1130	.1360	.0739	.0792	.0893	.9324
B	.0672	.0485	.0579	.0289	.0095	.0120	.0150	.0294	.0440	.0368	.0960	.1130	.1360	.0739	.0792	.0893	.9375
C	.0679	.0490	.0579	.0289	.0095	.0120	.0150	.0294	.0440	.0368	.0960	.1130	.1360	.0739	.0792	.0893	.9387
Colt M175CM	.0700	.0480	.0455	.0257	.0102	.0120	.0150	.0288	.0440	.0348	.0854	.1100	.1170	.0810	.0819	.0809	.8902
M5000CM	.0665	.0480	.0455	.0257	.0102	.0120	.0150	.0288	.0440	.0348	.0854	.1100	.1170	.0810	.0819	.0809	.8867
Envirovac	.0420	.0343	.0592	.0323	.0112	.0006	.0060	.0288	.0528	.0392	.0960	.1130	.1360	.0748	.0855	.0930	.9047
GATX ETS125	.0658	.0480	.0598	.0278	.0109	.0067	.0138	.0297	.0528	.0380	.0960	.1130	.1360	.0850	.0910	.0930	.9673
Thiokol MPB10	.0567	.0480	.0520	.0291	.0090	.0120	.0150	.0234	.0286	.0360	.0922	.1130	.1270	.0828	.0910	.0930	.9058

Table 13.(Cont'd)

Alternative \ Performance Measure	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Thiokol Navy System	.0581	.0466	.0514	.0278	.0100	.0120	.0150	.0288	.0490	.0340	.0922	.1130	.1220	.0829	.0892	.0930	.9240
St.Louis Ship FAST-15	.0000	.0020	.0624	.0326	.0106	.0028	.0150	.0285	.0127	.0376	.0960	.1130	.1360	.0828	.0910	.0902	.8142
Lundy UF5	.0161	.0279	.0546	.0295	.0108	.0048	.0060	.0294	.0253	.0372	.0941	.1130	.1310	.0810	.0855	.0930	.8392
Ocean System's Model	.0700	.0485	.0514	.0264	.0106	.0120	.0150	.0291	.0550	.0400	.0960	.1130	.1360	.0837	.0865	.0930	.9662
Westinghouse System	.0693	.0475	.0520	.0278	.0097	.0120	.0150	.0294	.0528	.0376	.0960	.1130	.1360	.0819	.0901	.0930	.9604
Koehler-Dayton MSTS	.0700	.0490	.0559	.0278	.0100	.0120	.0150	.0290	.0440	.0388	.0960	.1130	.1360	.0872	.0910	.0930	.9677
Seapax 20	.0546	.0436	.0533	.0288	.0107	.0042	.0114	.0279	.0391	.0388	.0960	.1070	.1360	.0765	.0828	.0921	.9028
50	.0630	.0466	.0533	.0288	.0107	.0035	.0114	.0279	.0391	.0388	.0960	.1070	.1360	.0765	.0828	.0921	.9135
100	.0665	.0475	.0533	.0288	.0107	.0006	.0114	.0279	.0391	.0388	.0960	.1070	.1360	.0765	.0828	.0921	.9150
FMC MSD 50-2000	.0644	.0480	.0592	.0288	.0096	.0120	.0123	.0282	.0330	.0336	.0931	.1070	.1280	.0730	.0828	.0884	.9011

Table 13. (Cont'd)

Alternative \ Performance Measure	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
FMC MSD 50-3000	.0700	.0490	.0592	.0288	.0096	.0120	.0123	.0282	.0330	.0328	.0931	.1070	.1280	.0730	.0828	.0884	.9065
50-4000	.0686	.0485	.0592	.0288	.0096	.0120	.0123	.0282	.0330	.0328	.0931	.1070	.1280	.0730	.0828	.0884	.9053
50-8000	.0616	.0480	.0592	.0288	.0096	.0120	.0123	.0282	.0330	.0328	.0931	.1070	.1280	.0730	.0828	.0884	.8978
Hyde System	.0490	.0402	.0624	.0330	.0103	.0120	.0141	.0285	.0528	.0356	.0883	.1060	.1120	.0748	.0892	.0911	.8993
Grumman 1500 Ozotherm	.0658	.0480	.0494	.0278	.0101	.0120	.0150	.0267	.0451	.0344	.0931	.1060	.1250	.0774	.0874	.0911	.9143
5000	.0630	.0480	.0494	.0278	.0101	.0120	.0150	.0267	.0451	.0344	.0931	.0106	.1250	.0774	.0874	.0911	.9115
25000	.0609	.0485	.0494	.0278	.0101	.0120	.0150	.0267	.0451	.0344	.0931	.1060	.1250	.0774	.0874	.0911	.9093
50000	.7000	.0490	.0494	.0278	.0101	.0120	.0150	.0267	.0451	.0344	.0931	.1060	.1250	.0774	.0874	.0911	.9195
Wilson's MACL 1500	.0700	.0475	.0527	.0226	.0088	.0120	.0150	.0282	.0440	.0392	.0000	.1090	.0000	.0712	.0910	.0930	.7042
2500	.0700	.0475	.0527	.0226	.0088	.0120	.0150	.0282	.0440	.0392	.0000	.1090	.0000	.0712	.0910	.0930	.7042

Table 13.(Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Wilson's 5000 MACL	.0700	.0480	.0527	.0260	.0088	.0120	.0150	.0282	.0440	.0392	.0000	.1090	.0000	.0712	.0910	.0930	.7047
G E's SWTS	.0476	.0461	.0442	.0285	.0084	.0120	.0150	.0270	.0528	.0328	.0864	.0961	.1220	.0800	.0737	.0818	.8544
Babcock & Wilcox SWD	.0238	.0171	.0605	.0326	.0107	.0120	.0150	.0290	.0550	.0384	.0960	.1130	.1360	.0846	.0910	.0930	.9077
Fram SP75	.0469	.0421	.0579	.0298	.0106	.0120	.0150	.0297	.0385	.0388	.0922	.0870	.1100	.0828	.0783	.0818	.8534
Incinelet	.0700	.0490	.0481	.0274	.0113	.0120	.0150	.0291	.0550	.0369	.0960	.1130	.1360	.0757	.0837	.0930	.9539
Destroilet	.0700	.0490	.0396	.0257	.0115	.0120	.0150	.0279	.0550	.0396	.0960	.1130	.1360	.0801	.0855	.0930	.9507
Wilcox-Crittenden, Holding Tank	.0700	.0475	.0529	.0230	.0078	.0120	.0000	.0225	.0550	.0400	.0960	.1130	.1360	.0837	.0865	.0911	.9440
Monogram Jet-O-Matic	.0700	.0485	.0624	.0319	.0114	.0098	.0039	.0294	.0528	.0396	.0960	.1130	.1360	.0872	.0892	.0921	.9712
Newmatic	.0700	.0485	.0644	.0319	.0114	.0098	.0039	.0294	.0528	.0396	.0960	.1130	.1360	.0872	.0892	.0921	.9732
Firestone Holding Tank	.0700	.0490	.0611	.0302	.0107	.0066	.0000	.0258	.0528	.0400	.0960	.1130	.1360	.0730	.0837	.0809	.9288

Table 13. (Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Sea Farer	.0700	.0490	.0637	.0326	.0098	.0120	.0000	.0282	.0550	.0396	.0960	.1130	.1360	.0854	.0819	.0893	.9301
Electra-Magic	.0700	.0490	.0637	.0326	.0098	.0120	.0000	.0291	.0550	.0396	.0960	.1130	.1360	.0854	.0855	.0911	.9678
Aqua Magic	.0700	.0490	.0637	.0333	.0097	.0120	.0000	.0282	.0550	.0396	.0960	.1130	.1360	.0863	.0874	.0911	.9703
Porta Potti	.0700	.0490	.0631	.0337	.0096	.0120	.0000	.0282	.0550	.0396	.0960	.1130	.1360	.0846	.0901	.0902	.9707
Mansfield Vacuum Flush	.0700	.0475	.0592	.0298	.0107	.0066	.0039	.0267	.0550	.0368	.0960	.1120	.1360	.0757	.0846	.0911	.9416
Aquatic Designs Holding Tank	.0700	.0480	.0579	.0250	.0077	.0120	.0060	.0225	.0550	.0396	.0960	.1130	.1360	.0837	.0855	.0911	.9090
Jonny TRap JT12	.0700	.0480	.0579	.0250	.0074	.0120	.0000	.0216	.0550	.0396	.0960	.1130	.1360	.0846	.0874	.0911	.9446
Potpourri	.0700	.0490	.0605	.0298	.0109	.0120	.0029	.0216	.0528	.0396	.0960	.1130	.1360	.0854	.0874	.0930	.9640
Kracor	.0700	.0475	.0605	.0302	.0107	.0098	.0039	.0261	.0550	.0392	.0960	.1130	.1360	.0872	.0892	.0930	.9676
Jensen 770	.0700	.0485	.0605	.0319	.0112	.0098	.0039	.0276	.0550	.0392	.0960	.1130	.1360	.0863	.0892	.0893	.9647

Table 13. (Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Bio-Pure BP6D	.0168	.0064	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0729	.0628	.0577	.5934
BP12D	.0175	.0098	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0729	.0628	.0577	.5975
BP20D	.0210	.0181	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0729	.0628	.0577	.6885
BP30D	.0196	.0167	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0730	.0629	.0577	.6066
BP50D	.0210	.0176	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0730	.0628	.0577	.6090
BP75D	.0231	.0216	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0730	.0628	.0577	.6150
BP100D	.0399	.0225	.0624	.0309	.0102	.0120	.0150	.0288	.0440	.0348	.0624	.0450	.0313	.0730	.0628	.0577	.6327
Red Fox RF3000M	.0126	.0064	.0605	.0278	.0104	.0120	.0150	.0258	.0539	.0376	.0912	.0260	.0410	.0694	.0592	.0549	.6037
Demco WT2200	.0280	.0074	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6347
WT325	.0175	.0025	.0818	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.5741

Table 13. (Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Demco WT625	.0224	.0039	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6406
WT1000	.0231	.0049	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6423
WT1250	.0266	.0064	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6473
WT1565	.0259	.0069	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6471
WT1875	.0301	.0078	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6487
WT2500	.0301	.0083	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6497
WT2875	.0308	.0088	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6532
WT3125	.0308	.0098	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6560
WT3750	.0280	.0083	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6506
WT6000	.0294	.0098	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6535

Table 13. (Cont'd)

Performance Measure / Alternative	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total Worth
Demco WT10000	.0329	.0113	.0618	.0285	.0102	.0120	.0150	.0288	.0490	.0344	.0902	.0590	.0310	.0712	.0637	.0595	.6585
Weldco	.0455	.0436	.0618	.0236	.0110	.0120	.0150	.0288	.0550	.0384	.0000	.0226	.0000	.0863	.0564	.0512	.5512
IWC M5000	.0504	.0460	.0618	.0319	.0110	.0120	.0150	.0291	.0127	.0392	.0912	.0475	.0762	.0846	.0592	.0558	.6917
Bio-Flo	.0686	.0372	.0546	.0305	.0103	.0120	.0150	.0237	.0440	.0328	.0576	.0790	.0410	.0703	.0564	.0549	.6759
Microphor M-10	.0693	.0485	.0624	.0205	.0110	.0102	.0150	.0195	.0528	.0392	.0000	.0140	.0000	.0579	.0446	.0391	.5061
M-12	.0672	.0475	.0624	.0205	.0110	.0120	.0150	.0196	.0528	.0392	.0000	.0140	.0000	.0579	.0446	.0391	.5027

: Same as "" in Table 8.

Cost Effectiveness

Cost, incident to this study, consists of the capital cost and the operating cost. Since the installation cost varies from vessel to vessel, the capital cost includes only the initial procurement cost for the equipment configuration. The initial procurement cost is reduced to an average annual cost over a ten-year system life. For evaluation purpose, both of the initial and operating cost are diminished to unit cost (dollars per 1000 gallons treated). The unit initial cost ($/1000 gallons treated) is obtained from the annual initial cost data and the average quantity of wastewater treated annually. Cost of money is excluded. The unit operating cost ($/1000 gallons treated) is estimated from the annually operating cost data and the average plant flow rate. The annual operating cost includes the cost of consumable chemicals, equipment, repairs, power, general operating maintenance labor, fuel, and pump out cost. It is assumed that electric power cost is at $ 0.01 per KWH, incinerator fuel at $ o.10 per gallon, manpower cost at $ 6.00 per hour, and pump out cost at $ 2.50 per 1000 gallons.

Results of the cost and effectiveness evaluations for 5 to 25 men, 50 to 75 men, 100 to 150 men, 200 to 300 men, and more than 500 men systems are summarized in Table 14, 15, 16, 17, and 18. To facilitate the identification of the most cost-effective systems, a set of figures, by plotting the alternative's cost versus its total utility, are prepared. Figure 40, 41, 42, 43, and 44 represent this purpose.

Table 14. Summary of Cost Effectiveness Analysis-

Alternative Disposal Devices for Vessels with 5-25 men

Alternative Systems(Ai)	Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost $/1000gal	Unit Operating Cost $/1000gal	Total Unit Cost $/1000gal	Total Worth
Aqua-San A1	20	13,000	400/yr.	5.4	1.66	7.06	.9227
GATX ETS125 A2	25	14,000	3.99/day	4.65	3.99	8.64	.9673
Thiokol MPB-10 A3	10	1000	1.00/day	0.84	2.50	3.34	.9058
St.Luois Ship FAST-15 A4	15	10,000	225.yr.	5.55	1.25	6.80	.8142
Ocean System Model A5	6	550	0.79/day	0.76	3.33	4.09	.9662
Westinghouse System A6	4	600(e)	0.94/day	1.25	5.86	7.11	.9604
Seapax 20 A7	20	10,000	2.4/day	4.17	3	7.17	.9028
Incinolet A8	4	645	75/yr.	1.34	1.56	2.80	.9539
Destroilet A9	4	350	70/yr.	0.73	1.50	2.23	.9507
Wilcox-Crittenden Holding TankA10	4	100	4.75/charge	0.21	5.40	5.61	.9680
Monogram Jet-O-Matic A11	4	525	4.50/charge	1.08	5.20	6.28	.9732

Table 14. (Cont'd)

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost	Unit Operating Cost	Total Unit Cost	Total Worth
Monogram Newmatic	A12	4	4.75	4.50/charge	0.99	5.20	6.19	.9753
Firestone Holding Tank	A13	4	50	3.29 per 1000gal	0.10	3.29	3.39	.9288
Sea Farer	A14	4	65	2.5/charge	0.14	7.70	7.84	.9301
Electra Magic	A15	4	160	2.5/charge	0.33	7.70	8.03	.9678
Aqua Magic	A16	4	100	2.5/charge	0.21	7.70	7.91	.9703
Porta Potti	A17	4	126	2.5/charge	0.27	7.70	7.94	.9707
Mansfield Vacuum Flush	A18	4	932	7.3/charge	1.94	9.02	10.96	.9416
Aquatic-Designs Tank	A19	6	145	4.0/week	0.20	4.50	4.70	.9480
Jonny Trap	A20	4	140	4.7/1000gal	0.30	4.7	5.00	.9446
Potpourri	A21	4	89	2.46/charge	0.19	5.75	5.94	.9640
Kracor	A22	6	124	2.20/charge	0.17	6.50	6.67	.9676
Jensen	A23	4	125	2.30/charge	0.26	4.27	4.33	.9647
Bio-Pure	A24	10	4435	3.59/1000gal	3.69	3.59	7.28	.5934

Table 14. (Contd)

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost	Unit Operating Cost	Total Unit Cost	Total Worth
Bio-Pure	A25	20	5095	3.06/1000gal	2.12	3.06	5.18	.5975
Demco								
WT325	A26	8	3970	200/yr.	6.63	3.3	9.93	.5714
WT625	A27	16	4896	220/yr.	4.08	1.83	5.91	.6406
WT1000	A28	25	5150	250/yr.	2.87	1.39	4.26	.6423
WT1250	A29	32	5370	270/yr.	2.24	1.13	3.37	.6473
Bio-Flo	A30	4	400(e)	5.0/mo.	0.83	1.04	1.87	.6759

(e): Estomated.

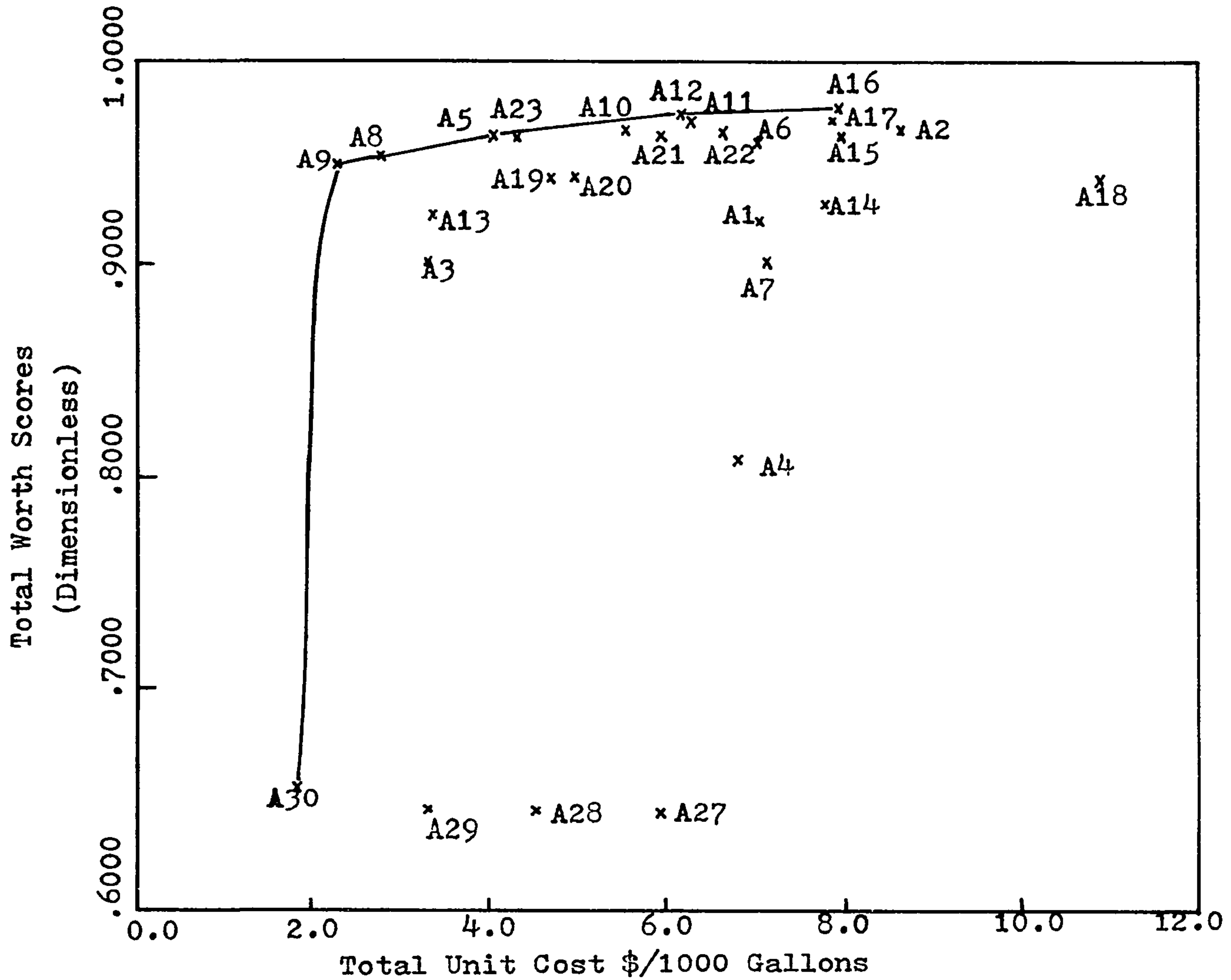

Figure 40. Relationship between Total Unit Cost and Total Worth Scores of Various Alternative Systems Suitable for Installation at 5-25 men Vessels.

Table 15. Summary of Cost Effectiveness Analysis-

Alternative Disposal Devices for Vessels with 50 - 75 men

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost	Unit Operating Cost	Total Unit Cost	Total Worth Scores
Aqua-San A-1	A1	50	17,000	800/yr.	2.84	1.33	4.17	.9324
Seapax 50	A2	50	13,000	900/yr.	2.16	1.5	3.66	.9135
Ozotherm	A3	50	40,000	4/1000gal	6.6	4.0	10.6	.9143
Bio-Pure BP20D	A4	35	6175	2.76/1000gal	1.44	2.76	4.20	.6085
BP30D	A5	50	7580	1.37/1000gal	1.26	1.37	2.63	.6066
BP50D	A6	80	11280	0.93/1000gal	1.16	0.93	2.09	.6090
Red-Fox	A7	75	17520	62/yr.	1.95	0.10	2.05	.6037
Demco WT2200C	A8	55	6090	350/yr.	1.45	9.83	2.28	.6347
WT1565C	A9	40	5690	300/yr.	1.89	1.0	2.89	.6471
WT1875C	A10	47	5890	330/yr.	1.64	0.92	2.56	.6587
WT2500C	A11	62	6550	365/yr.	1.36	0.77	2.13	.6497
WT2815C	A12	70	6615	380/yr.	1.22	0.70	1.92	.6532
WT3125C	A13	78	6745	400/yr.	1.12	0.66	1.78	.6460

Table 15. (Cont'd)

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost	Unit Operating Cost	Total Unit Cost	Total Worth Scores
Weldco	A14	50	20,000	360/yr.	3.33	0.60	3.93	.5512
IWC M5000	A15	100	15900	2400/yr.	1.34	2.0	3.34	.6917

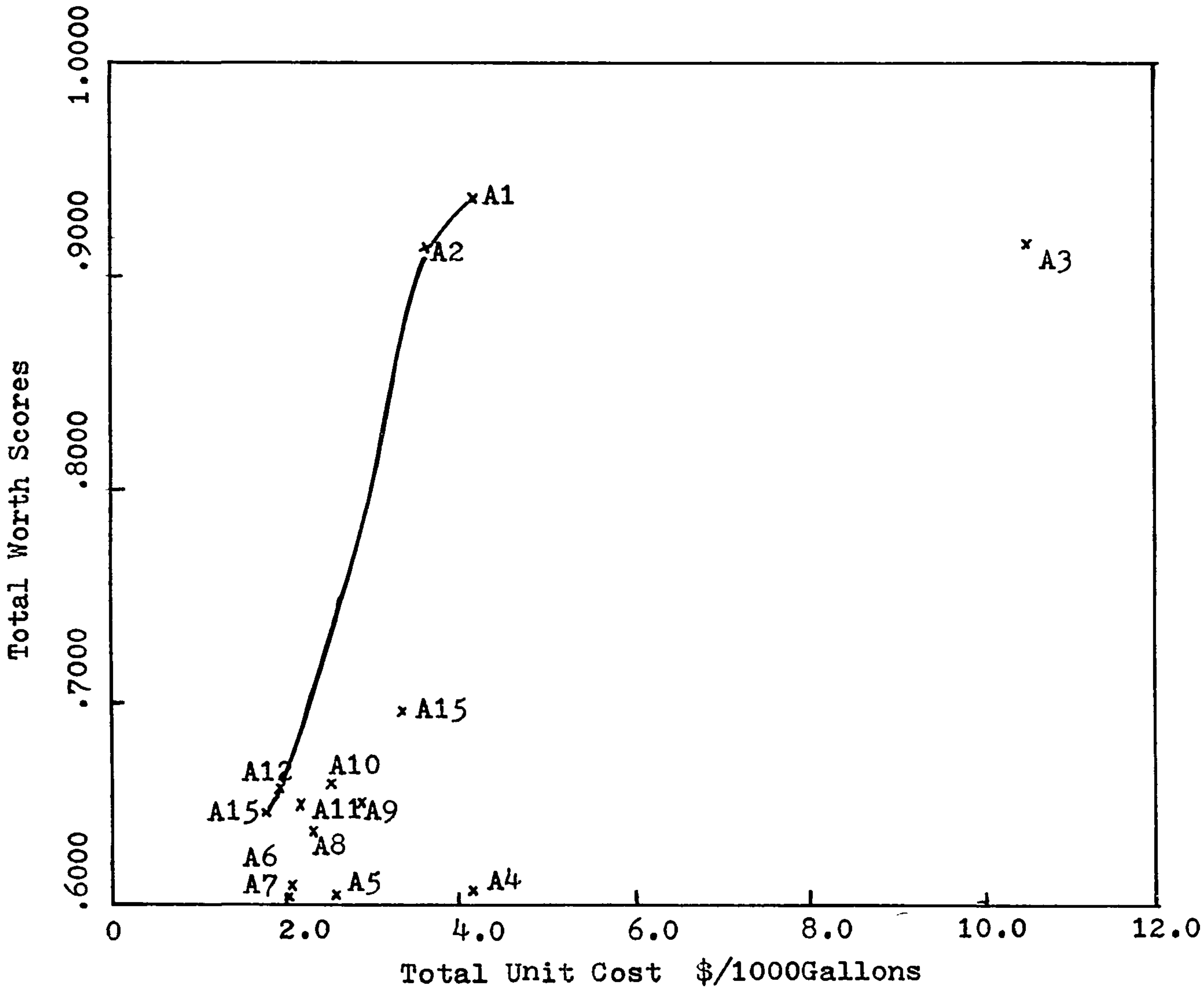

Figure 41. Relationship Between Total Worth Scores and Total Unit Cost of Various Alternative Systems Suitable for Installation At 50 to 75 Men Vessels

Table 16. Summary of Cost Effectiveness Analysis-

Alternative Disposal Devices for Vessel with 100 - 150 Men.

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost	Unit Operating Cost	Total Unit Cost	Total Worth Scores
Jered VACU BURN	A1	150	18000	22/day	1.0 per 1000gallons	3.66/1000gal	4.66	.9311
Aqua-San B	A2	125	24000	1500/yr	1.5	1.0	2.5	.9375
Lundy UF5	A3	125	80000	8800/yr	5.33	1.75	7.08	.8392
Seapax 100	A4	100	15000	12/day	1.25	1	2.25	.9150
FMC 50-2000	A5	100	22500	1.5/1000gal	1.88	1.50	3.30	.9011
Hyde System	A6	150	48000	6000/yr	2.67	3.33	6.00	.8993
Ozotherm	A7	125	60000(e)	10/1000gal	4.0	3.19	7.19	.9115
GE's SWTS	A8	100	55000	3500/yr	4.57	2.92	7.49	.8544
Babcock& Wilcox SWD	A9	120	70000	18.25/day	4.85	3.76	8.61	.9077
BioPure BP75D	A10	120	14985	0.68/1000gal	1.04	0.68	1.74	.6150
BP100D	A11	180	16000	0.52/1000gal	0.74	0.52	1.26	.6327
Demco WT3750C	A12	94	7440	420/yr.	1.03	0.86	1.89	.6506

Table 16. (Cont'd)

Alternetive System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost $/1000gal	Unit Operating Cost $/1000gal	Total Unit Cost $/1000gal	Total Worth Scores
Demco								
WT5000C	A13	125	8096	445/yr	0.85	0.46	1.31	.5912
WT6000C	A14	150	8715	470/yr	0.76	0.42	1.18	.6535
WT7000C	A15	175	9380	500/yr	0.71	0.38	1.09	.6542

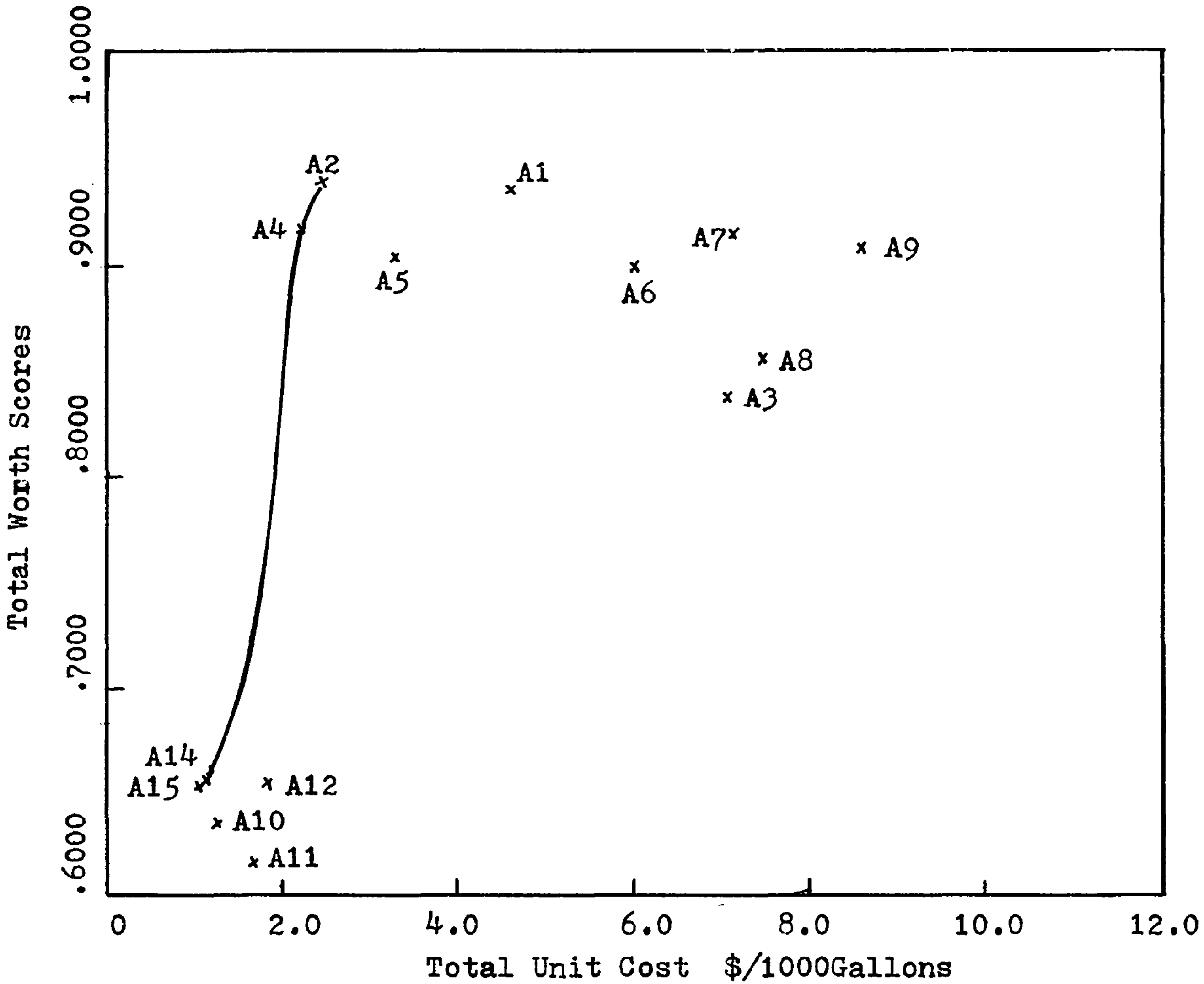

Figure 42. Relationship Between Total Worth Scores and Total Unit Cost of Various Alternative Systems Suitable for Installation At 100 to 150 Men vessels.

Table 17. Summary of Cost Effectiveness Analysis-

Alternative Disposal Devices for Vessels with 200 - 300 Men.

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost $/1000gal	Unit Operating Cost $/1000gal	Total Unit Cost $/1000gal	Total Worth Scores
Aqua-San C	A1	320	27000	2800/yr	0.71	0.73	1.44	.9387
Colt M175CM	A2	200	40000(e)	3.55/day	1.67	0.36	2.03	.8902
Thiokol Navy System	A3	200	40000(e)	1.00/day	1.67	0.10	1.77	.9240
FMC MSD 50-3000	A4	200	26000	1.5/1000gal	1.08	1.5	2.85	.9064
Fram SP75	A5	200	38000	5889/yr	1.58	2.45	4.03	.8534
Demco WT8000C	A6	200	10080	525/yr	0.65	0.34	0.99	.6435
WT9000C	A7	225	10510	550/yr	0.61	0.32	0.93	.6592
WT10000C	A8	250	10925	575/yr	0.57	0.30	0.87	.6585
WT12500C	A9	320	13800	600/yr	0.58	0.38	0.96	.6270
Koehler-Dayton MSTS	A10	200	40000	1000/yr	1.60	0.40	2.00	.9677

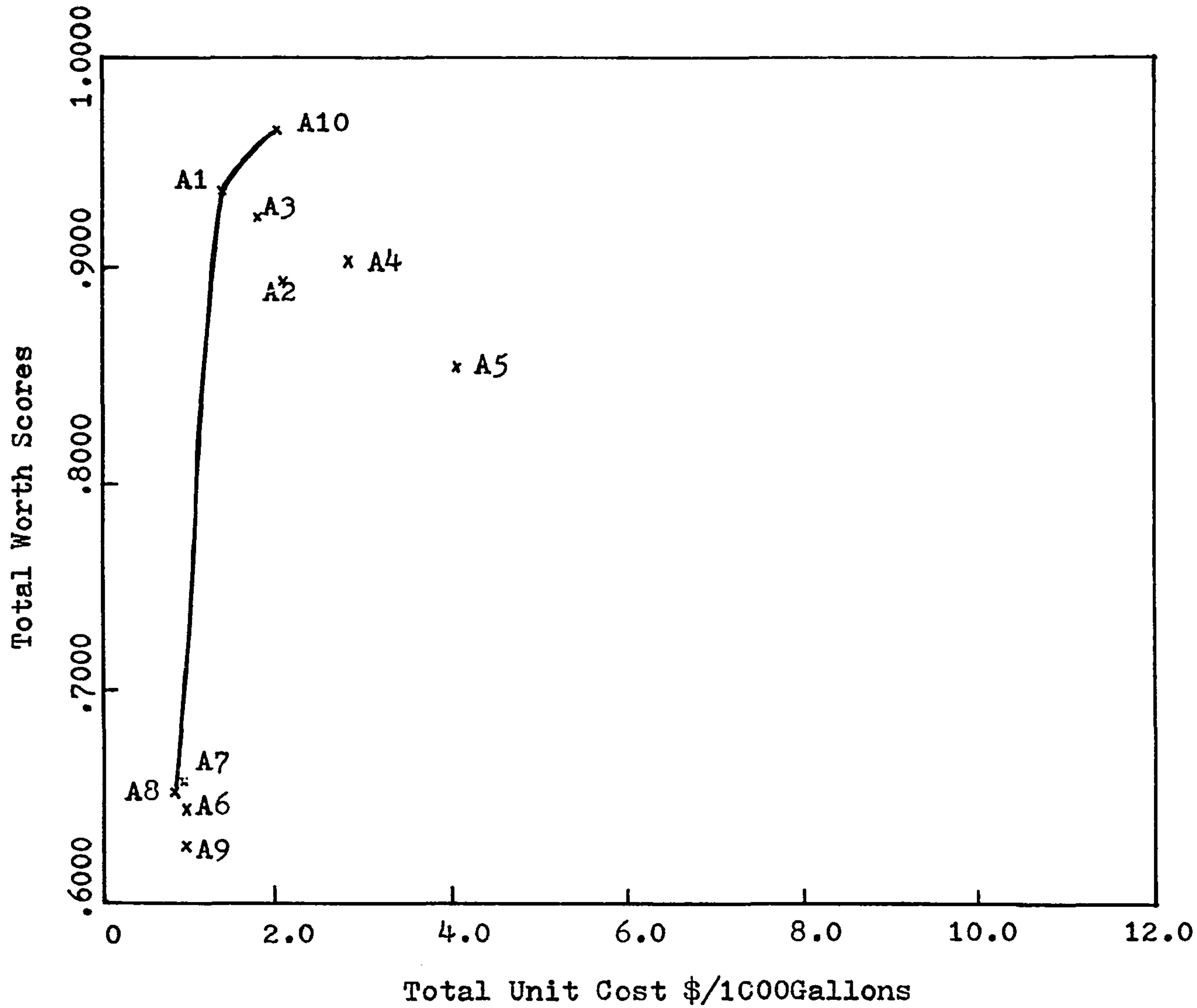

Figure 43. Relationship Between Total Worth Scores and Total Unit Cost of Various Alternative Systems Suitable for Installation At 200 to 300 Men Vessels.

Table 18. Summary of Cost Effectiveness Analysis-

Alternative Disposal Devices for Vessels with More Than 500 men.

Alternative System (Ai)		Man Basis	Initial Procurement Cost	Operating Cost	Unit Capital Cost $/1000gal	Unit Operating Cost $/1000gal	Total Unit Cost $/1000gal	Total Worth Scores
Colt M500CM	A1	500	55000 (e)	7.27/day	0.92	0.46	1.38	.8867
FMC MSD 50-8000	A2	500	40000	1.5/1000gal	0.66	1.50	2.16	.8978
Ozotherm	A3	600	75000 (e)	2.9/1000gal	1.04	2.91	3.95	.9033

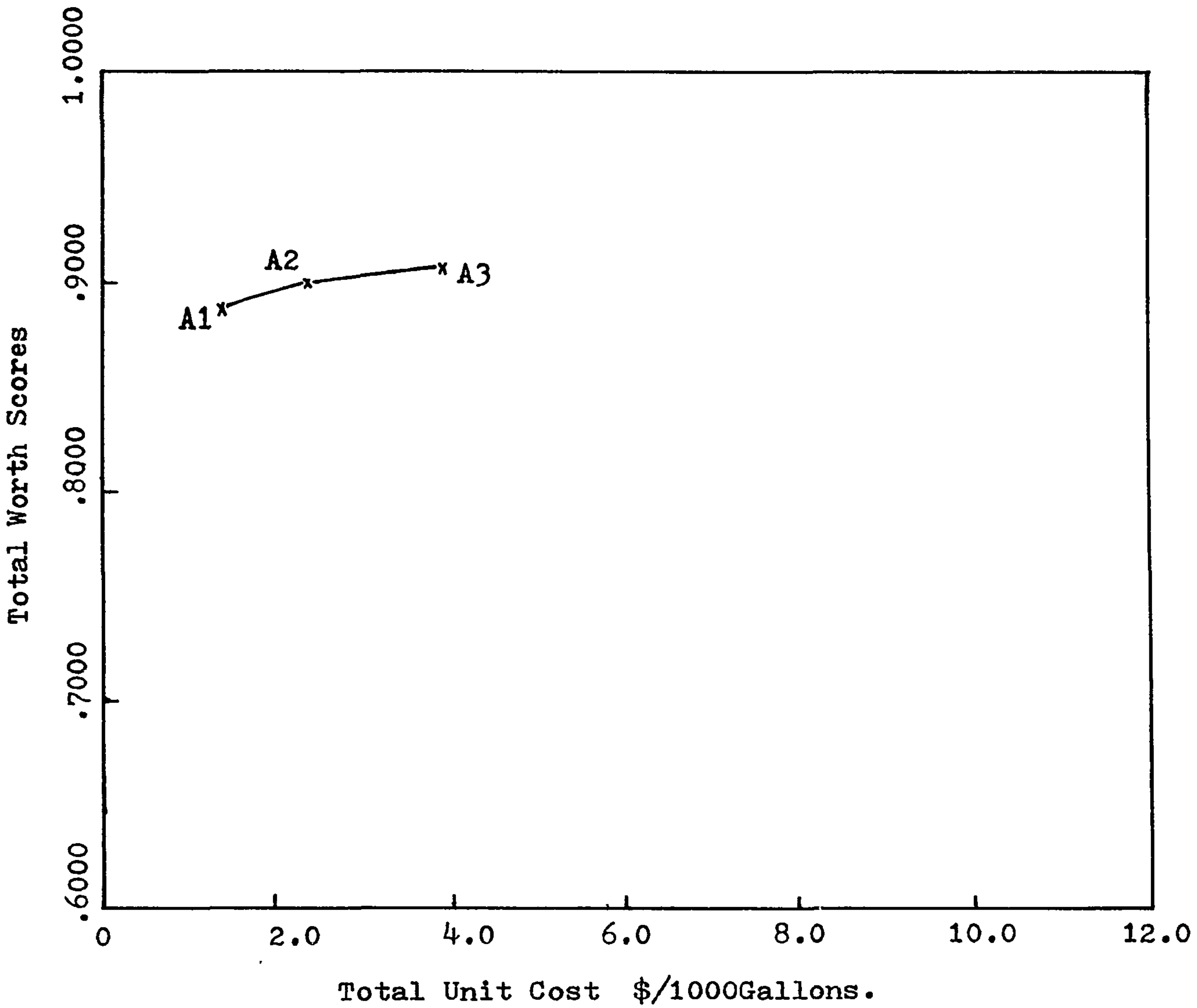

Figure 44. Relationship Between Total Worth Scores and Total Unit Cost of Various Alternative Systems Suitable for Installation At Vessels with More Than 500 Men.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

In order to insure that no reasonable alternative was overlooked in evaluating the total utility of the alternatives based on the physical weight of the equipment and the space requirement of the equipment, all alternatives were analyzed by considering the wet weight of the equipment and the net space requirement of the equipment excluding the working space.

Systems such as the macerator-chlorinator which were not designed to remove the suspended solids and BOD contents from the waste stream were excluded before the evaluation because of their inability to produce secondary treatment effluent.

It should be noted that the graphical scoring functions summarized in Figure 39 and the weighting functions represent the opinions of ship owners, ship operators, and ship manufacturers who have operating experience in commercial vessels with crew sizes of approximately twenty. Since every individual vessel has its own operating characteristics regarding its mission, it is necessary to make an adjustment on the graphical scoring functions and weighting functions when applying this study to select an optimum shipboard sewage disposal device for the individual vessel. However, those directly estimated scoring functions which were evaluated mainly on the process characteristics are valid for any situation.

A detailed examination of the evaluation indicates that the biological treatment devices are scored low in the aspects of space requirement, weight requirement, environmental quality control, and reliability. A relaxation of space and weight requirements in large sea-going vessels, such as tankers, will certainly yield an increase in total utility. Holding tank systems have high scores in the performance criteria except the shoreside facilities dependency. It is obvious that for vessels with more flexible missions, such as the recreational watercraft, the holding tank systems generally are more economical and reliable than the others. Physical-chemical treatment systems are high in total utility but are not economic for smaller vessels. The operating cost is usually high compared to the other treatment methods. Furthermore, they are complicated in nature and require specially trained personnel. Vacuum collection systems show the advantage of a reduction in the use of liquids for cleaning and transport of all forms of sanitary wastes. However, their total unit treatment cost compensates for this advantage.

There is no marketed shipboard sewage disposal device that is highly effective and economical for all types of vessels. It appears that more research work is needed. In stead of looking at the shipboard sewage disposal devices separately from the overall vessel sanitation problem, they should be considered as a part of the entire system. The best answer will come from a thorough consideration of all elements of the sanitary system and the functioning of the total system in coordination with the mission of the vessel. Surplus heat, pressure, air, and other forms of energy are usually available on all powered vessels to some degree and can be used to advantage in the waste treatment processes. Space occupied by consumables could be fitted with expandable retention containers that fill with waste as stores or liquids as consumed. The development of sanitary waste handling systems for future vessels should be undertaken with full recognition of all such possibilities.

The conclusions obtained from this study are presented with respect to the method of analysis and the criteria of equipment design.

The method applied in this study furnishes a rational procedure to specify what is desired from whatever alternatives have been produced, then evaluate these alternatives in such a way that reflects the entire spectrum of desired characteristics to reach a final decision. The potential of this method is far beyond the application in this study. It can be easily extended to any other comparison of commercial equipment, to locating resource spending, and to integrating the separate worth and resource consaquences to arrive a final decision.

It can be ascertained visually, from Figures 40,41, 42, 43, and 44, shipboard sewage disposal devices designated A9, A8, A5, A10, A12. A11, and A16 are the most effective systems in the group suitable for installation at 5 to 25 men vessels, A2 and A1 for 50 to 75 men vessels, A2 and A4 for 100 to 150 men vessels, A1 and A10 for 200 to 300 men vessels, and A1 for more than

500 men vessels. This may be determined by using the following decision rule. If a system, e.g., Ai has a greater cost but lesser or equal effectiveness than other system, i.e., Aj, Ai is eliminated. Repeated applications of this elimination procedure leaves systems which are linked with a solid line in each figure.

A critical inspection of these figures indicates that A30 of Figure 40, A13 of Figure 41, A15 of Figure 42, A8 of Figure 43, and A1 of Figure 44 are the least costly of all systems in each group but are the least effective; system A16, A1. A2, A10, and A3 in Figure 40, 41, 42, 43, and 44 respectively, although having the highest effectiveness, are also most expensive. The curves possess two distinct ranges, for instance in Figure 40, one below and one above system A9. The range below system A9 has a higher slope than that above, indicating that systems in the lower range yield a greater gain in effectiveness for any given incremental cost than do systems in the range above system A9. The sharp change in the slope at system A9 is a break point, indicating that the system is highly cost effective as compared to the others. Other alternatives such as A8, A5, A10, A12, A11, and A16 exhibit a nearly linear relationship between cost and effectiveness. Selection of any of these systems would depend upon how much one can afford to pay for the additional effectiveness gain.

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20. Manufacturer Supplied Information, Thetford Corporation, Dexter, Michigan.

21. Bulletin No. M-515-R, Mansfield Sanitary, Inc. Perrysville, Ohio 44864

22. Manufacturer Supplied Information, Aquatic Designs, Inc., New York.

23. Manufacturer Supplied Information, Singer Co. Chicago, Ill.

24. Manufacturer Supplied Information, Sanitary Equipment Inc., Elkhart, Indiana.

25. Manufacturer Supplied Information, The Joseph B. Stinson Co. Fremont, Ohio.

26. Catalog S-301/1-73/5M, Jensen General Corporation, Los Angels,

27. Manufacturer Supplied Information, Kracor, Inc., Milwaukee.

28. Manufacturer Supplied Information, Craftor Inc., New York.

29. Catalog No. 512-73 R, Drew Chemical Corp., Parsippany, N.J.

30. Manufacturer Supplied Information, Red Fox Industries, Inc. New Iberia, Lousisiana.

31. Catalog WT-72, Demco Inc., Oklahoma City, Oklahoma.

32. Manufacturer Supplied Information, The Youngstown Welding and Engineering Co., Youngstown, Ohio.

33. Bulletin No. 473-1, International Waste Controls, Inc. Elmsford, New York.

34. Manufacturer Supplied Information, Pure Way Corp., Moline, Ill.

35. Manufacturer Supplied Information, MicroPhore, Inc., Willits, California.

36. Manufacturer Supplied Information, Jered Industries, Inc., Brimingham, Michigan.

37. Manufacturer Supplied Information, Chrysler Corp., New Orleans, Louisiana.

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41. Manufacturer Supplied Information, Lundy Electronics and Systems, Inc. Glen Head, New York.

42. Manufacturer Supplied Information, Westinghouse Electric Corp., Pittsburgh,

43. Manufacturer Supplied Information, Litton, Koehler-Dayton, Britain, Connecticut.

44. Manufacturer Supplied Information, Seapax, Inc., Cleveland.

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49. Manufacturer Supplied Information, Wilson Water Purification Corp., Buffalo, New York.

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52. Manufacturer Supplied Information, Research Products Manufacturing Co., Dallas, Texas.

53. Manufacturer Supplied Information, LaMere Industries, Inc. Walworth, Wisconsin.

54. File 7014, Colt Industries.

55. Manufacturer Supplied Information, General American Transportation Corp., Niles, Ill.

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61. Manufacturer Supplied Information, Ocean Systems, Inc., Reston, Virginia.

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APPENDIX 1

Please check if a copy of the report is desired _____

MFG ____________ Model ____________ Date ____________

1. Could you supply us with a detailed assembly diagram and a flow diagram of your device.

2. Weight of the device (#) dry ________ wet ________

3. Capacity (gal./day) ________________________

4. How many men basis ________________________

5. Size ____________

6. Estimated price $___________ 7. Estimated annual cost of operation ______________

8. All weather capability ____________

9. Is odor a problem? __________

10. Influent concentration
    BOD _____________ PPM
    Suspended
    Solid ________ PPM

    Effluent concentration
    BOD _____________ PPM
    Suspended
    Solid ________ PPM
    Coliform ________

11. Are chemical additives required? _____
    What is the chemical _________ Strength of the chemical _____

12. What kind of disinfectant is used? _________________
    Strength of the disinfectant ______________________

13. Power requirement __________ 14. Fuel requirement _________

15. Are shoreside facilities required? ________

16. Service life (estimated) ____________

17. Anything you think important _________________________________

18. Hours of care required per day. _____________________________________

APPENDIX 2

If you know more than one type of vessel, could you supply us with as many as possible cases you know.

1. Crew size of the vessel: __________

2. Purpose of the vessel: Fishing __, Recreation __, Commercial __, Other (please specify) ____________________

3. In <u>each</u> of the following groups, would you please assign your feeling of "weight of importance" to each of the items in the group. It is preferred that the sum of the weights in each group equals to one (1). For instance, in Group I, after reviewing your feeling, you may give 15% to a., 15% to b., 20% to c., 30% to d., and 20% to e.

GROUP I:
- a. Compatibility with shipboard environment _______%
- b. Simplicity of operation of the shipboard sewage disposal device _____%
- c, System effectiveness (ability of the disposal device to meet legislative regulations) _____%
- d. Reliability _____%
- e. Cost of the device ______%

GROUP II:
- a. Space Requirement of the disposal device ______%
- b. Weight requirement ______%
- c. Safety effect _____%
- d. Esthetic effect _____%

GROUP III:
- a. Shore-side facility dependency _____%
- b. Degree of automation ____%
- c. Supervision hours required ____%
- d. Specialist dependency _____%

GROUP IV: a. Effluent quality _____%

b. Potential to meet no-discharge requirement _______%

GROUP V: a. Possibility of critical parts in malfunction ______%

b. Sensitivity to ambient change _______%

c. Sensitivity to raw material change _______%

In the following questions, score one (1) means that you have been completely satisfied by the device's figure, score zero (0) means nothing can be worse than that. Numbers between 0 and 1 means that you are only partially satisfied with the device.

4. Based on "ft^3/man"** of space requirement, to your opinion, what sizes of the shipboard sewage disposal device will have:

Score	0.0	0.2	0.3	0.4	0.6	0.8	1.0
Space requirement of the sewage disposal device							

**If a disposal device has a volume of Aft^3 and is capable of serving B persons, then its "ft^3/man" value is $\frac{A}{B}$.

5. Based on "#/man", when the disposal device will have"

	0.0	0.2	0.4	0.6	0.8	1.0
Weight Requirement (#/man)						

6. Based on hours required to pump out the stored sewage from the disposal device ashore each time, when the disposal device will have:

Score	0.0	0.2	0.4	0.6	0.8	1.0
Hours required to pump out the stored sewage ashore.						

7. Based on times/week required for shore-side service, when the disposal device will have:

Score	0.0	0.2	0.4	0.6	0.8	1.0
Times/week						

8. Based on hours/week required for supervision, when the disposal device will have:

Score	0.0	0.2	0.4	0.6	0.8	1.0
hours/week						

APPENDIX 3

ORGANIZATIONS AND PERSONNEL CONTACTED

U.S. Government Agencies

1.Department of the Navy Naval Facilities Engineering Command Washington D.C.	J.B. Groff Commander, CEC, USN
2.U.S. EPA National Environmental Research Center Edison, N.J.	David J. Cesareo Sanitary Engineer
3.Wastewater Technology National Sanitation Fundation Ann Arbor, Mich.	Heinz B. Russelmann Director
4.U.S. Army Corps of Engineers Washington D.C.	William Murden Chief, Plant & Supply Branch
5.Department of the Navy Naval Ship Research and Development Center Headquarters Bethesda, Md.	H.H. Singerman Hd. Pollution Abatment Division
6.Water Pollution Control New York State Department of Enviromental Conservation Albany, N.Y.	Mr.Philip De Gaetano
7.Tennessee Valley Authority Chattanooga, Tennessee	Dr. E.E. Gartrell Director of Environ- mental Research and Development
8.Department of the Navy Naval Ship Research and Development Center Headquarters Bethesda, Md.	D.H. Kallas Hd. Material Department

Shipboard Sewage Management System Manufacturers

1.The Cleveland-Cliffs Iron Co. Cleveland, Ohio	Mr. John Horton Assistant Manager Marine Department

2. Seapax, Inc. 1898 Cater Road Cleveland, Ohio	Mr. Alex McDougall Mr. Robert H. Lucas
3. Ametex 5825 District Blvd. Los Angeles, Calif.	Mr. S.E. Summers Chief Engineer
4. Zimpro, Inc. Rothschild, Wisc.	Mr. R. B. Ely
5. Hercules, Inc. Industrial System Department 900 Greenbank Road Wilmington, Delaware	Mr. R. H. Baldwin
6. Monogram Industries, Inc. 1165 E. 230th St. Carson, Calif.	E. F. Mckirnan Sale Manager Marine Sanitation Systems
7. Thetford Corp. 7931 Grand St. Dexter, Mich.	Mr. Orbie E. Lind, Jr. Marine Project Engineer
8. Mansfield Sanitary, Inc. Perrysville, Ohio	Mr. A. J. Drouhard Sales Manager
9. Aquatic Designs, Inc. 7000 E. Genesee St. Fayetteville, N.J.	
10. Sanitation Equipment Inc. 615 S. 4th St. Elkhart, Indiana	
11. The Joseph B. Stinson Company Fremont, Ohio	
12. Jensen General Corporation Los Angeles, California	Mr. Ed. Johnson Vice President
13. Kracor, Inc. Milwaukee	
14. Craftor, Inc. Latham, New York	Mr. Frank W. Mayock
15. Firestone Coated Fabrics Company Magmelia, Arkansas	Mr. C. T. Klavon
16. Drew Chemical Corporation Parsippany, New Jersey	

17.	Red Fox Industries, Inc. New Iberia, Louisiana	Mr. D. W. Sullivan Chief Engineer
18.	Demco Inc. Oklahoma City, Oklahoma	Paul Sturdivan Product Manager
19.	The Youngstown Welding and Engineering Company Youngstown, Ohio	
20.	International Waste Controls, Inc. Elmsford, New York	Mr. J. L. Winterstella
21.	Pure Way Corporation E. Moline, Illinois	
22.	Microphor, Inc. Willits, California	Mr. E. L. Bruce Sale Manager
23.	Pall Trinity Micro Corporation Pall Corporation Cortland, New York	
24.	Jered Industries, Inc. Birmingham, Michigan	Mr. Michael Brian
25.	Space Division Chrysler Corporation New Orleans, Louisiana	Mr. Ralph W. Loomis
26.	Colt Industries Beloit, Wisconsin	Mr. P. K. Bissell Mr. P. A. Weiss
27.	Thiokol Wasatch Division Brigham City, Utah	Mr. T. J. O'Grady Manager Mr. P. H. Woolkiser
28.	St Louis Ship Division of the Pott Industries, Inc. St. Louis, Missouri	Mr. E. K. Lortz
29.	Lundy Electronics and System Inc. Glen Head, New York	Mr. R. M. Berry
30.	Westinghouse Electric Corporation Pittsburgh, Pa.	Mr. A. B. Turner
31.	Koehler-Dayton New Britain, Connecticut	Mr. R. E. Delaney
32.	FMC Corporation San Jose, California	Mr. R. W. Vaugham Manager

33. Hyde Products, Inc. Westlake, Ohio	Mr. T. P. Mackey,
34. General Electric Company Philadephia, Pa.	Mr. John Federico
35. Grumman Aerospace Corporation Bethpage, New York	Mr. J. J. Mikals Manager
36. Wilson Water Purification Corporation Buffalo, New York	Mr. C. L. Barzycki President
37. Babcock & Wilcox Barberton, Ohio	Mr. R.E. Munholland
38. Fram Corporation Pawtucketm R. I.	Mr. J. H. White Project Engineer
39. Research Products Manufacturing Company Dallas, Texas	Dr. E. B. Blankenship President
40. LaMere Industries, Inc. Walworth, Wisconsin	Mr. D. P. Frankel President
41. General American Transportation Corporation Niles, Illinois	MR. P. A. Saigh Program Manager ETS System Mr. G. A. Dorth Director of Technical Products
42. Wilcox-Crittenden Company Middletown, Connecticut	
43. Apollco Corporation Victoria, Minnesota	Mr. R. A. Alott
44. Raritan Engineering Company Millville, N.J.	Mr. G. W. Crowell
45. Dravo Corporation Pittsburgh, Pa.	Mr. A. M. Martinson
46. Hydronautics, Inc. Laurel, Md.	Mr. A. Gollan Principal Research Scientist
47. General Dynamics Groton, Connecticut	Mr. H. Wallman Chief, Enviromental Engineering

48. Petmann Corporation Dunnedin, Florida	Mr. W. J. Hargraves
49. RSC Industries, Inc. Hialeah, Florida	Mr. J. M. Richardson Chairman
50. Vapor Corporation Chicago Illinois	
51. Ocean Systems, Inc. Reston, Virginia	Mr. J. S. Brown
52. Pollution Control Industries, Inc. Wayne, Pa.	Mr. E. L. Kaminsky

Marine Vessel Operators

1. General Recreational, Inc. Albuquerque, New Mexico	Mr. R. A. Patterson Vice President
2. Hunt Tool Company Houston, Texas	Mr. Dale Williamson
3. Federal Barge Lines, Inc St. Louis, Missouri	Mr. R. A. Labdon Marine Superintendent
4. Department of the Navy Naval Ship Research and Development Center Bethesda, Md.	Mr. H. H. Singerman Hd. Pollution Abatement Division
5. Lockhead Shipbuilding Construction Company Seattle, Washington	Mr. R. L. Stevenson Engineering Group Manager, O&E Ship Systems
6. Union Mechling Corporation Pittsburgh, Pa.	Mr. A. H. Edwards Vice President, Engineering
7. Chris & Craft Corporation Pompano Beach, Florida	Mr. Peter C. Ball Director
8. Richard Bertram & Company Miami, Florida	Mr. D. F. Pottinger Manager
9. Jay R. Benford & Asso, Inc. Friday Harbor, Washington	Mr. Herman Husen

10. Delta Steamship Lines, Inc. New Orleans	Mr. L. Field Supt. Engineer
11. Waterman Steamship Corporation New York	Mr. R.S. Walsh Vice President
12. U. S. Steel Corporation New York	Mr. C. F. Benkema Vice President
13. American Mail Line, Ltd. Seattle, Washington	Mr. H. A. Greenwood Vice President
14. Seatrain Lines, Inc. New York	Mr. Howard M. Pack
15. American Shipbuilding Company Cleveland, Ohio	Mr. C. W. Elliot President
16. Pott Industries, Inc St. Louis, Missouri	Mr. Noble C. Parsonage
17. Griffen Industries, Inc. Miami, Florida	Mr. L. D. Brinkman
18. CVR Industries, Inc Richmond Hill, New York	Mr. M. D. Kantor
19. Baber Steamship Lines, Inc. New York	Mr. W. J. Shields
20. American Foreign Steamship Corporation New York	Mr. R. F. Butter Engineer